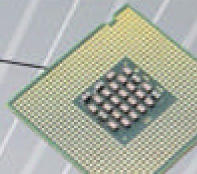
NEW

GADGETS & FUTURE TECH | ENTERTAINMENT | ENGINEERING | BIOTECH

Fusing man and machine

Homes of the future

GUIDES TO ALL THE LATEST TECH


Technology goes micro

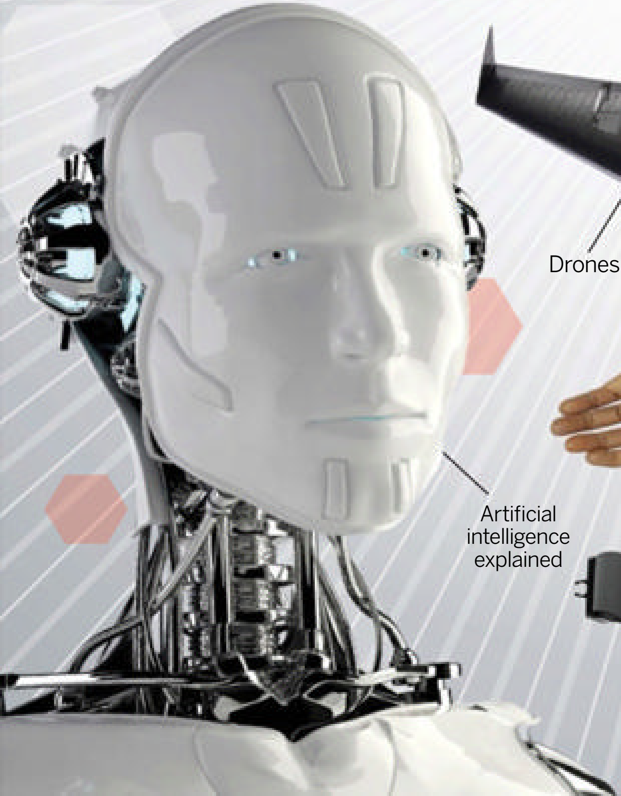
Designing a virtual world

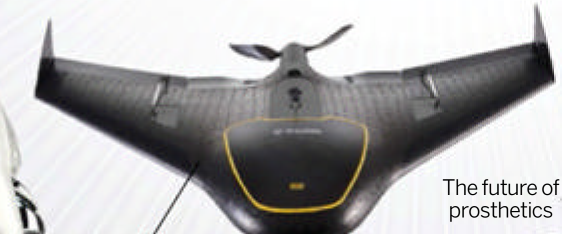
Life-saving technology

# HOW IT WORKS BOOK OF AMAZING TECHNOLOGY

Vol. 3

EVERYTHING YOU NEED TO KNOW ABOUT THE WORLD'S BEST TECH


Artificial intelligence explained


Drones

The future of prosthetics

The dawn of virtual reality

Wearable technology

WELCOME TO

# HOW IT WORKS BOOK OF AMAZING TECHNOLOGY

Vol. 3

Technology affects societies all over the world, with some parts being significantly more technologically developed than others. The debate about whether technology helps or hinders human beings is ongoing, but few of us actually understand how it all works. The revised edition of the How It Works Book Of Amazing Technology Volume 3 will educate and inform readers about some of the world's most innovative gadgets, impressive constructions and unbelievable developments in artificial intelligence. With our in-depth guides, fascinating facts and detailed cutaway images, you'll learn about everything from the latest wearable tech to spacesuits that keep astronauts alive. Find all the answers to your technology-related questions right here.

HOW IT WORKS
BOOK OF

# AMAZING TECHNOLOGY

Vol.3

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IMAGINE
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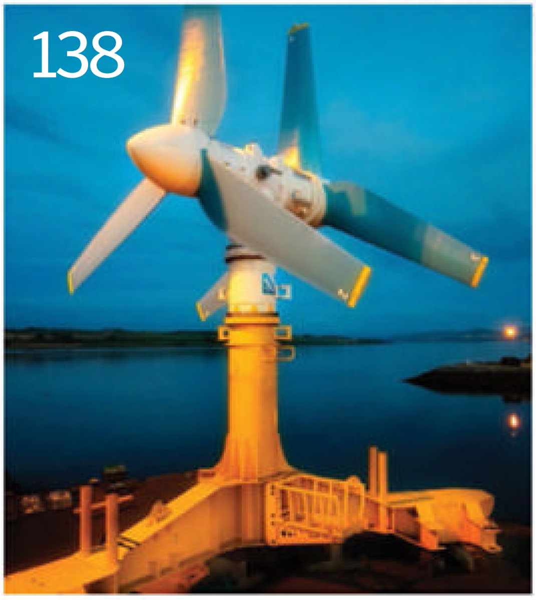

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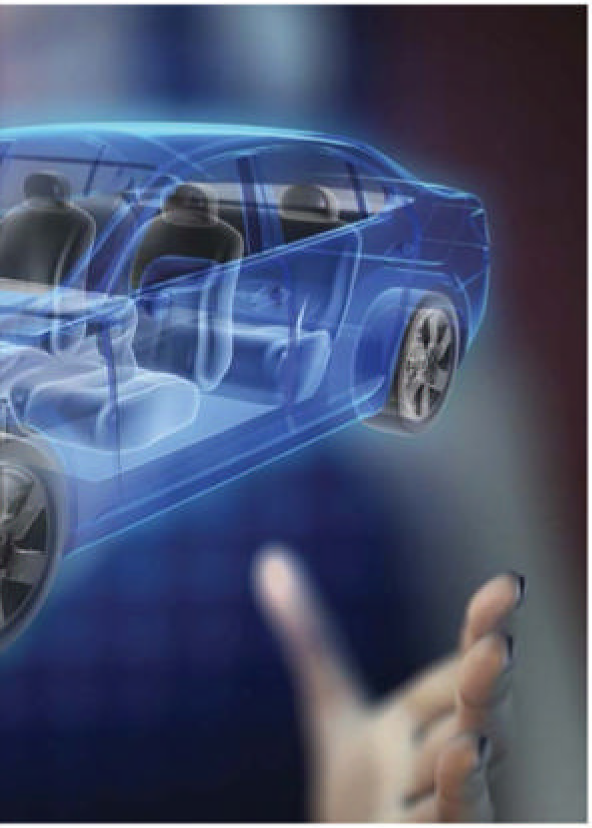

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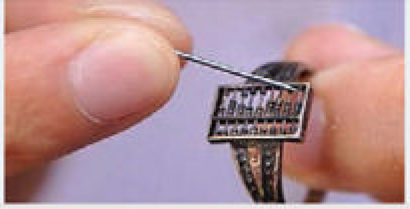
# Apple Watch

## +10 AMAZING NEXT-GEN WEARABLE GADGETS

**STRANGE BUT TRUE**
**ADD IT UP**

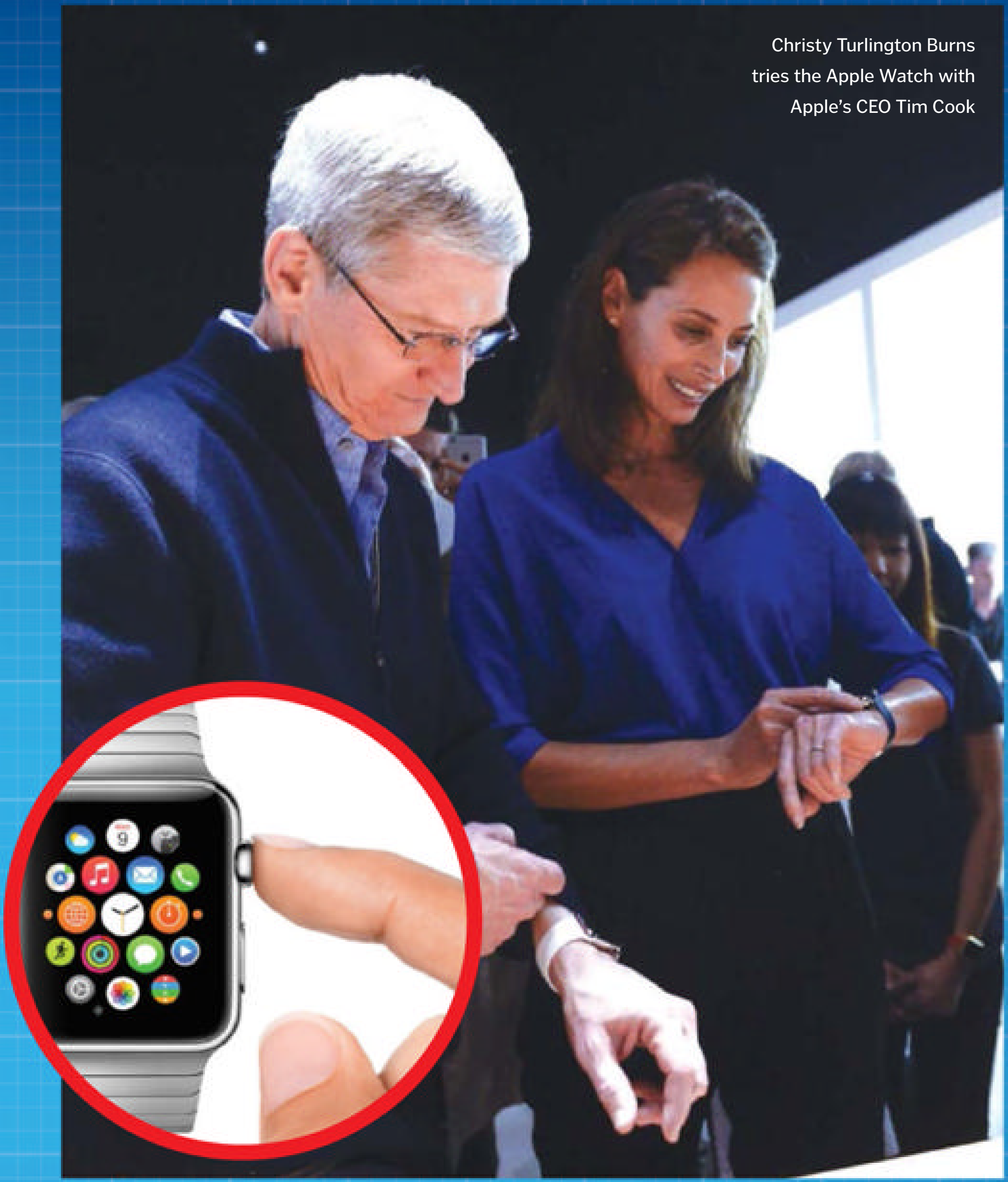
## What did the first wearable computer look like?

**A** An abacus on a ring **B** A digital wristwatch
**C** A brilliant Hallowe'en costume

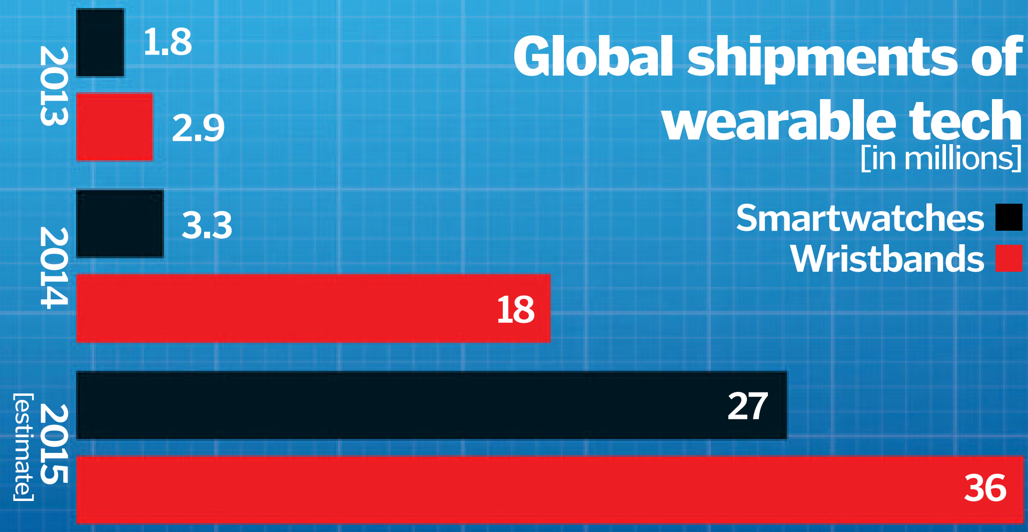


**Answer:**
In the 17th century, the Chinese Qing dynasty created a tiny (1cm by 0.5cm / 0.4in by 0.2in) but fully functioning silver abacus on a ring. The computer could be used to count and make calculations while it was being worn.

**DID YOU KNOW?** *Wearable tech was the most tweeted-about topic at CES 2014, ahead of 3D printing and the Internet of Things*



Christy Turlington Burns tries the Apple Watch with Apple's CEO Tim Cook



### Global shipments of wearable tech

[in millions]

Today, the gadgets we carry are becoming less an extension of ourselves, and more and more a part of us. "Wearables" are electronic or computing devices that are worn on the body – performing functions like tracking, biosensing and mobile communications – and we're about to see a lot more of them.

The ultimate aim of all wearables is to provide portable, seamless and mostly hands-free access to 'life-enhancing' functions. To date, by far the most successful wearables have been fitness trackers that record things like physical activity, heart rate and sleep quality, but many analysts believe we're on the cusp of a wearables revolution.

That revolution was undoubtedly spurred on by the launch of one of the most talked-about wearable devices of all time: the Apple Watch. Achieving commercial release in April 2015, it was the subject of much rumour, speculation, hype and even prayers for at least five years. So what has the must-have gadget of the decade brought to the table?

The Watch was created as a companion device to the iPhone, which means you can make calls, send messages and surf the web right from your wrist once the two devices are paired. It also comes with a slew of sensors to monitor your fitness, and is able to authorise Apple Pay transactions when in contact with its PIN-verified owner's fingerprint. Interaction with the device feels new too – thanks to a Digital Crown dial used to navigate the touchscreen without obscuring it, and a haptic feedback engine that can literally tap you on the wrist.

It's not all good news for wearables, though. Arguably as eagerly anticipated as the Apple Watch was the face-worn optical display Google Glass. Despite prototypes being trialled by early adopters and developers over the last couple of years, it failed to gain traction and, as of 19 January 2015, is on hiatus.

Wearables are pressing ever onward, though. Look out for devices becoming less bulky, less obvious and even implantable. Celebrated futurist Ray Kurzweil – who correctly predicted Wi-Fi and voice commands – reckons that within five years, we'll wear glasses that can beam images direct onto our retinas. He also predicts that by 2045 we'll be able to multiply our intelligence by a factor of a billion by wirelessly linking our brains' neocortexes to the Cloud. Talk about mind-blowing stuff! ▶

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## Will it change the face of wearable technology?

The hotly anticipated Apple Watch went on sale 24 April 2015 and there are 38 different versions available. These include two different face sizes, 38 millimetres (1.5 inches) and 42 millimetres (1.7 inches), to suit smaller and larger wrists, and multiple strap and metal variations. Prices range from £299 ($349) for the basic Sport model to £13,500 ($17,000) for the top-of-the-range 18-karat gold Apple Watch Edition. In fact, Apple has invented a new kind of gold for its luxury timepiece. Rather than combining three parts gold with one part silver or copper, which are standard metals used in alloys, Apple has used ceramic instead, a low-density material that makes the gold twice as hard and more resistant to scratches.

You can expect to get about 18 hours of typical everyday use out of your Watch between charges, but the battery life can be extended to about 72 hours if you activate the Power Reserve feature that turns most of the functions off. It will then take approximately 2.5 hours to go from zero to full charge when you clip on the wireless charger.

As well as being able to accurately tell the time to within 50 milliseconds via the customisable face, the Watch can also run a variety of other functions when paired with an iPhone 5, 5C, 5S, 6 or 6 Plus. It can be used to make and take phone calls via the built-in speaker and microphone, receive and send text messages by dictating them, selecting from preset templates or simply selecting an emoji, and it can track your fitness using a variety of built-in sensors. However, it can only measure the distance you travel when you have your GPS-enabled phone with you too.

Thousands of apps have also been developed for the Watch, enabling you to access social networks such as Facebook and Instagram, summon a taxi via Uber and identify the name of a song using Shazam. It will also come in very useful when travelling, as you'll be able to use it as your boarding pass at the airport and as your room key when you get to the hotel.

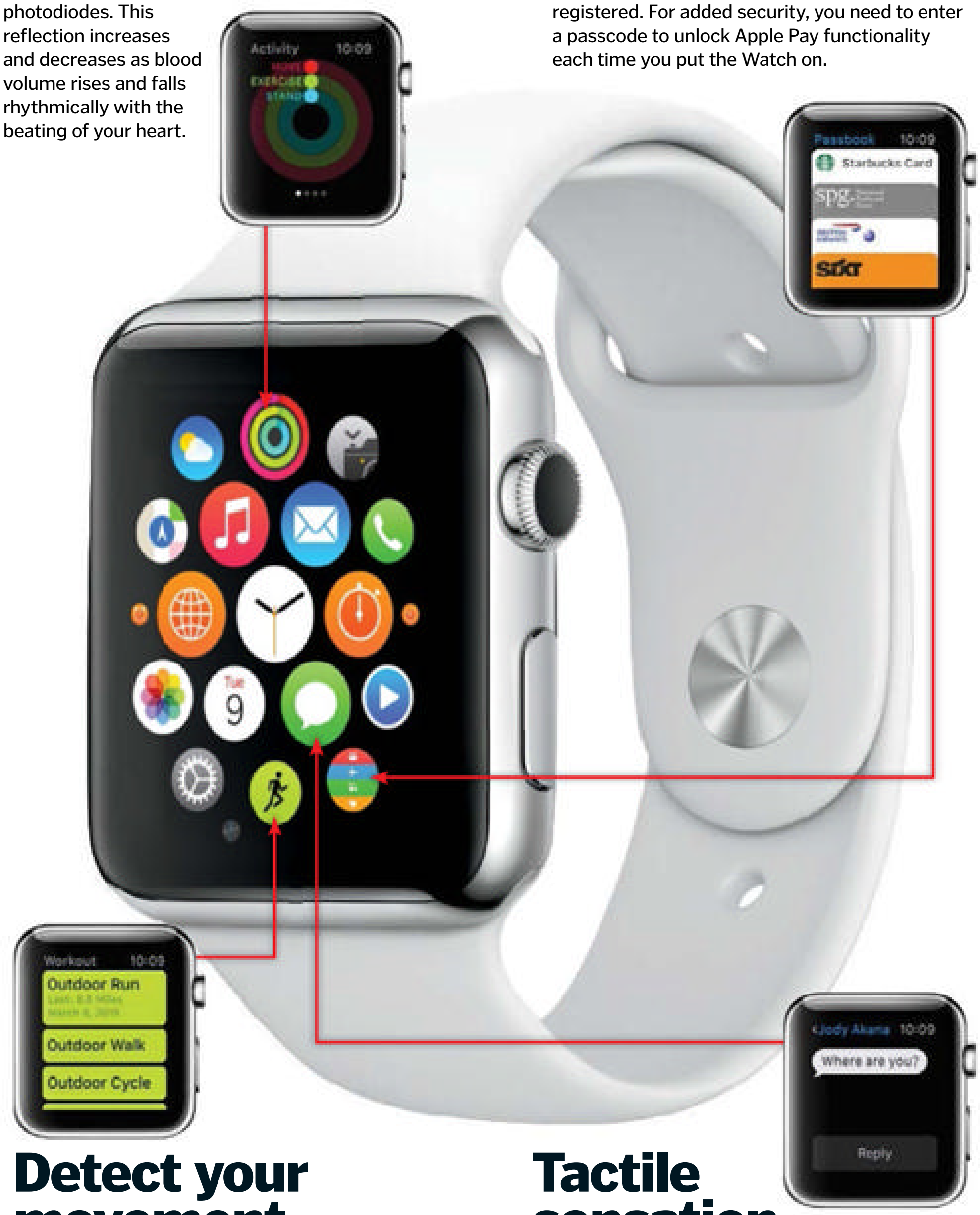
> "Thousands of apps have been developed"

## Monitor your heart rate

Behind a set of four sapphire lenses on its back cover, the Apple Watch's custom heart-rate sensor uses infrared and visible-light LEDs and photodiodes to measure your pulse. When light from the LEDs shines onto your wrist, a portion of it is reflected by the blood in the arteries just beneath the skin, and registered by the photodiodes. This reflection increases and decreases as blood volume rises and falls rhythmically with the beating of your heart.

## Pay for your shopping

First you need to add your credit card details to the Apple Watch app on your iPhone. When you pay for your shopping, you tap the button on the side of the Watch twice and place the face against the payment terminal. This transmits a unique placeholder code to your bank, which matches it up to the account details you registered. For added security, you need to enter a passcode to unlock Apple Pay functionality each time you put the Watch on.



## Detect your movement

Accelerometers measure acceleration, tilt, force and vibration, by means of electrical components that produce voltage in proportion to the physical movement of tiny mobile masses within the device. The Apple Watch uses an accelerometer to detect all kinds of physical movement – from standing up to working out – to monitor your activity levels and track your fitness. It senses when you raise your wrist and the Watch responds by displaying the screen for you.

## Tactile sensation

The Taptic Engine is a unique haptic feedback vibrator that lets the Apple Watch deliver physical sensations to your wrist. It gives you a discreet tap when you receive a message, helps you get someone's attention with a remote tap, and even lets you send your own heartbeat to someone who's got it racing. The forces on the skin are created by tiny motors called actuators, which can produce a range of recognisably different sensations for each type of interaction.

**THE STATS**
**WATCH THIS**

**2.5 hours** CHARGING TIME

**10.5mm** THICKNESS

**£299** STARTING PRICE

**38mm** SMALL SCREEN HEIGHT

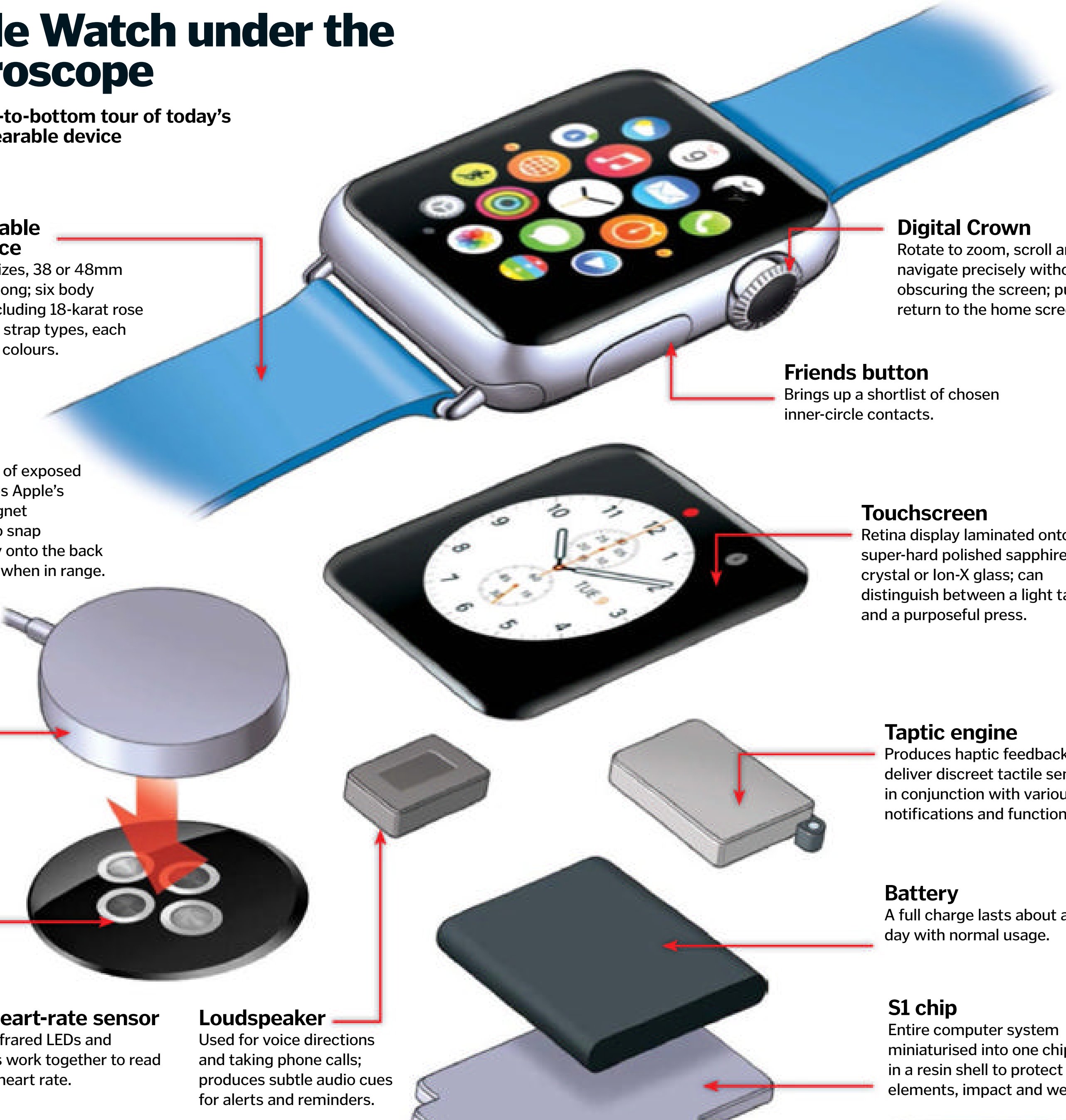
**42mm** LARGE SCREEN HEIGHT

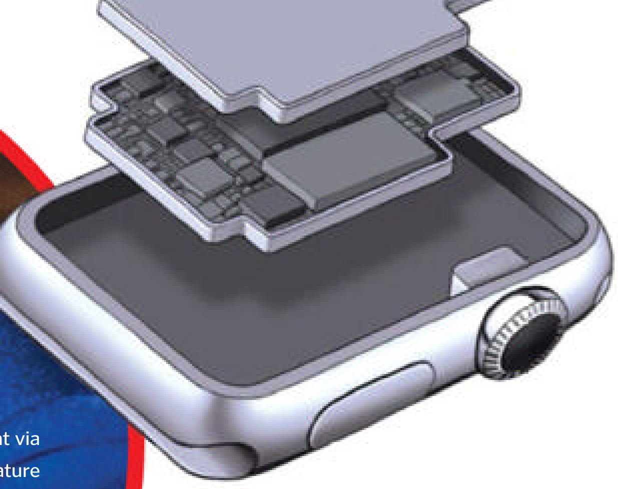
TYPICAL BATTERY LIFE **18 hours**

**DID YOU KNOW?** *The Watch doesn't have a built-in camera, but can be used to remotely control your iPhone lens*

# Apple Watch under the microscope

**Take a top-to-bottom tour of today's hottest wearable device**





**Customisable appearance**
Two screen sizes, 38 or 48mm (1.5 or 1.9in) long; six body materials (including 18-karat rose gold); and six strap types, each with multiple colours.

**Induction charger**
Safe and free of exposed contacts; uses Apple's MagSafe magnet technology to snap automatically onto the back of the Watch when in range.

**Digital Crown**
Rotate to zoom, scroll and navigate precisely without obscuring the screen; push to return to the home screen.

**Friends button**
Brings up a shortlist of chosen inner-circle contacts.

**Touchscreen**
Retina display laminated onto super-hard polished sapphire crystal or Ion-X glass; can distinguish between a light tap and a purposeful press.

**Taptic engine**
Produces haptic feedback to deliver discreet tactile sensations in conjunction with various notifications and functions.

**Battery**
A full charge lasts about a day with normal usage.

**S1 chip**
Entire computer system miniaturised into one chip, encased in a resin shell to protect it from the elements, impact and wear.

**Custom heart-rate sensor**
Visible and infrared LEDs and photosensors work together to read the wearer's heart rate.

**Loudspeaker**
Used for voice directions and taking phone calls; produces subtle audio cues for alerts and reminders.

Contactless payment via Apple Pay will be a feature of the Apple Watch

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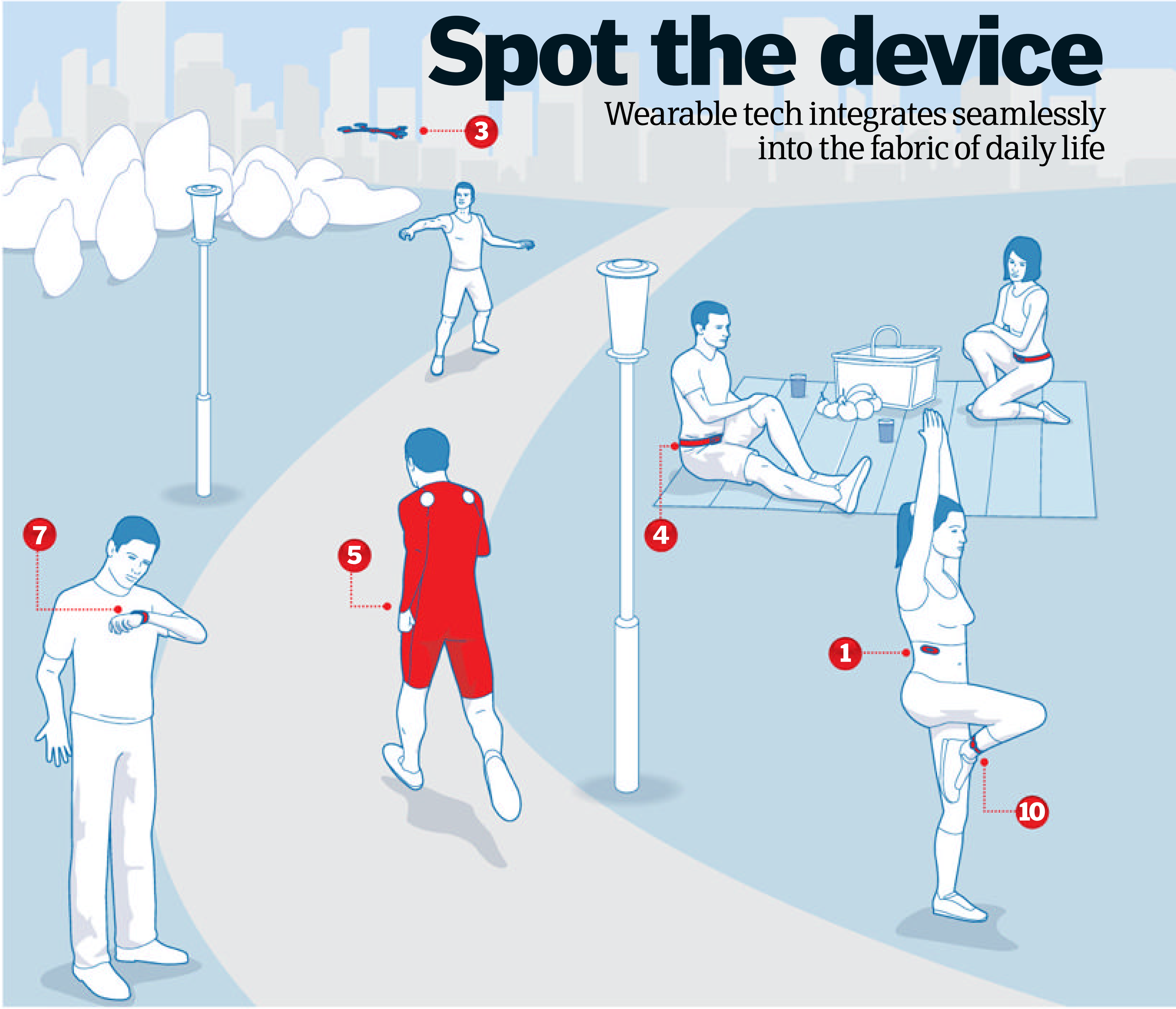
# Spot the device

Wearable tech integrates seamlessly into the fabric of daily life



## 1 Heart-rate monitor stickers

AmpStrip is a 24/7 wearable heart-rate and activity monitor that sticks to the skin of the torso like a waterproof plaster. Its echocardiogram (ECG) sensor uses a pair of electrodes to capture the timing of electrical signals produced by the heart as it beats, while its accelerometer tracks posture, activity type and intensity of activity.

## 2 Smart gloves

ProGlove is a sensor-loaded smart glove designed to improve efficiency, performance and safety of factory workers. It performs optical scanning and identification of goods, tools and parts; motion tracking to prevent missed steps in production processes; and heart-rate monitoring to help the wearer avoid physical burn-out during work.

## 3 Wearable drone

Taking narcissism to a whole new level, Nixie is the world's first wearable drone camera. When not in use, its four arms cling to the wrist just like a bracelet, however, the arms unfold on cue and the Nixie then takes flight. Like a boomerang, it arcs through the air taking selfie shots from new dramatic perspectives, leaving the wearer free to pose.

## 4 Smart belt

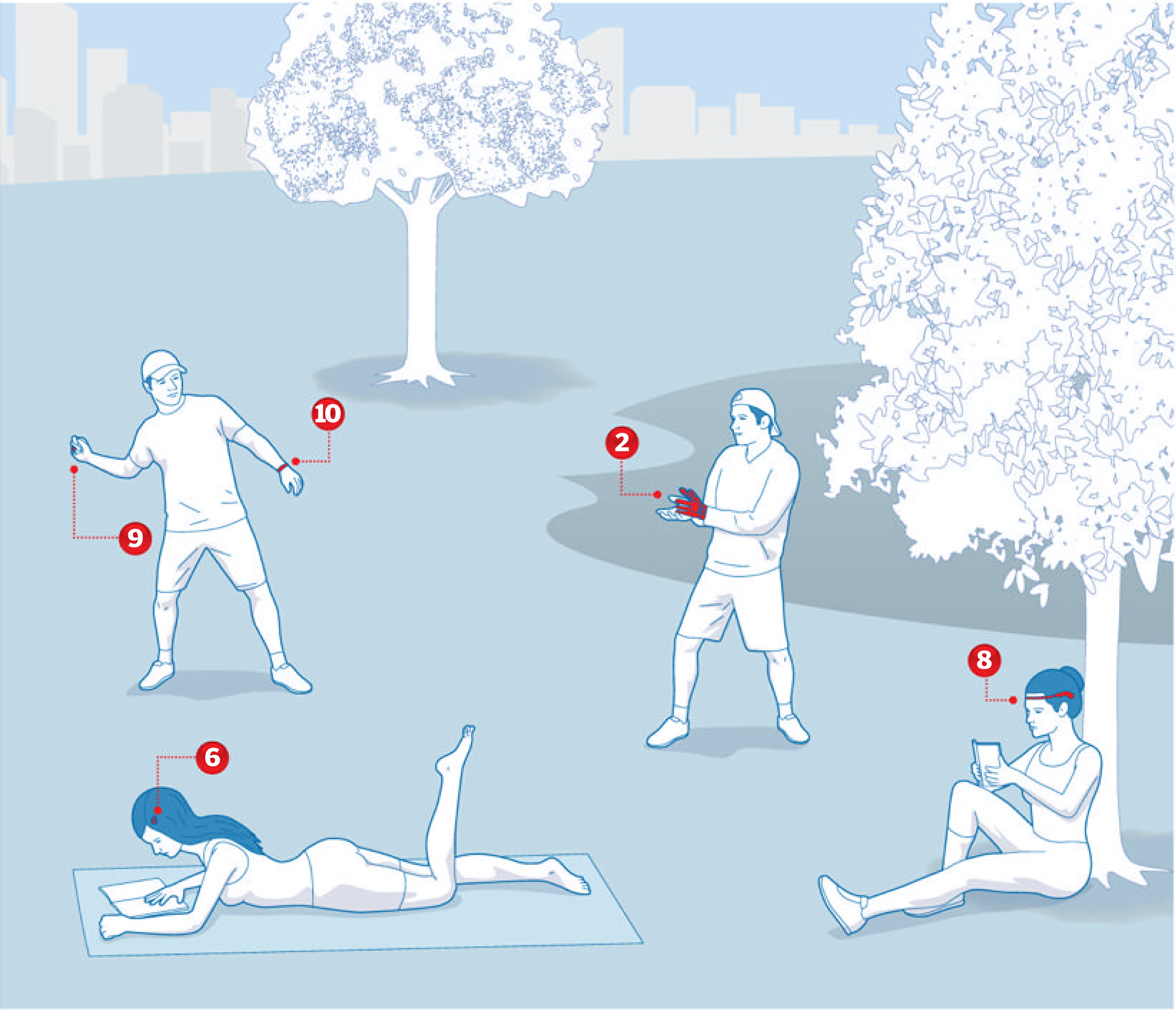
The Belty smart belt uses pressure sensors and actuators in order to tighten or loosen itself to the wearer's preferred level of comfort as their waistline expands and contracts throughout the day. It also houses a pedometer – nudging the wearer if they've been sedentary for too long – and connects with an app for long-term analysis.

## 5 Smart fabrics

Smart fabrics give the wearer information about their body movements. XelfleX textiles have optical fibres woven into them, which scatter light differently as the wearer's joints bend and flex. Sensoria socks have pressure sensors that relay information about foot strike to a Bluetooth anklet, and a smartphone app helps wearers improve their running technique.

*"Ampstrip is a wearable activity monitor that sticks to the skin of the torso like a plaster"*

**DID YOU KNOW?** *48% of people plan to buy a wearable in the next year, and 20% already own at least one device*



## 6 UV hairclip

The Solitair app analyses a person's natural pigmentation from a picture of their skin and combines this with geographical location and weather forecast data to give an individual daily recommendation for safe Sun-exposure time. A UV sensor, worn in the hair or on a lapel, registers exposure and alerts the wearer when it's time to seek shade.

## 7 Smartwatch

Samsung's Gear S smartwatch is a giant curved watch and smartphone all in one. Just like a smartphone, it has its very own 3G service and SIM card, and wearers are able to make hands-free calls either by speakerphone or via a Bluetooth headset. It also supports messaging, email, fitness monitoring, news blasts, maps and apps.

## 8 Brain-sensing headband

Muse is a brain-sensing headset that measures electrical brain signals via a set of seven electroencephalography (EEG) sensors that are positioned around the band. Users are then able to study their brain in real-time, as they perform exercises that are designed to increase focus, reduce stress, or improve their ability to keep calm under pressure.

## 9 Smart ring

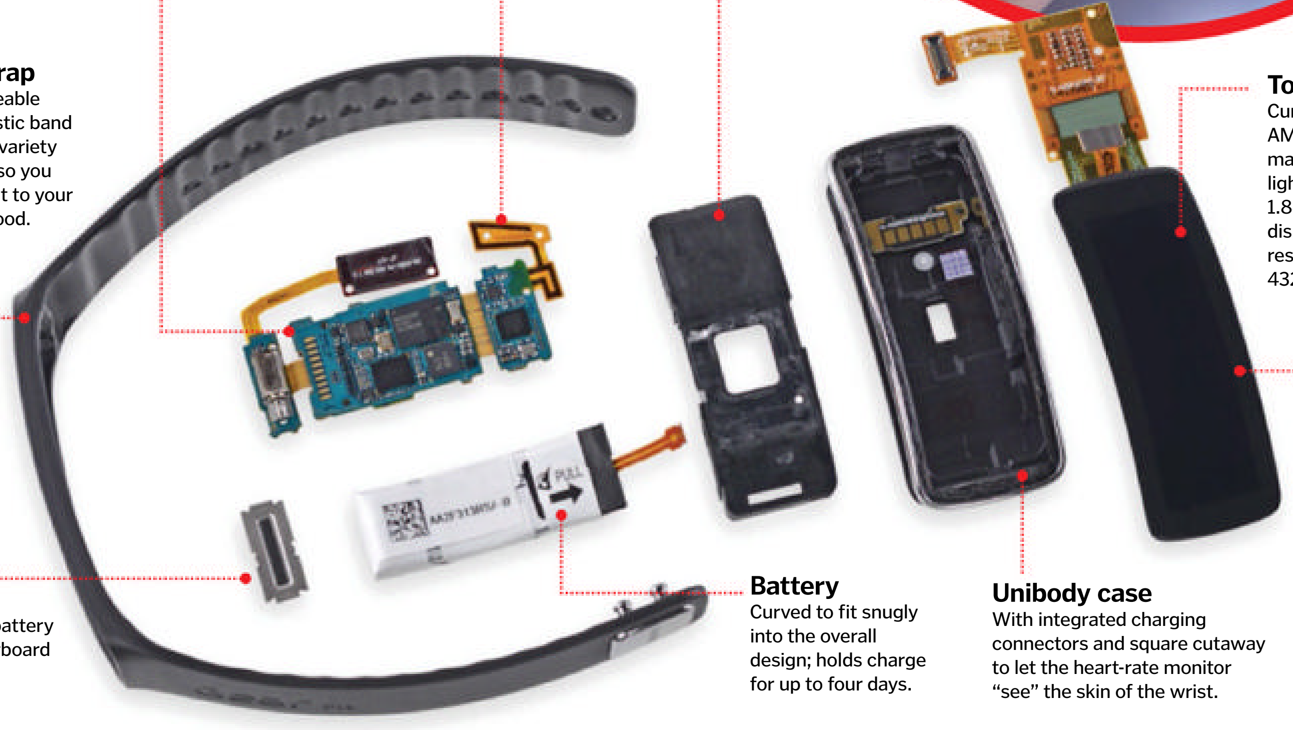
The Mota smart ring keeps smartphone notifications at its wearers' fingertips, even when their smartphones are not. The ring pairs to the wearer's phone via Bluetooth, and flashes up important notifications in the form of subtle text, audio or tactile alerts, leaving the wearer to decide whether to interrupt what they are doing to respond or not.

## 10 iFitness tracker

Moov is a nine-axis motion-sensing system that maps the wearer's movements, offering suggestions for improved pace and body positioning in sports from swimming to cardio boxing. Its disc-shaped body houses a magnetometer, gyroscope and accelerometer. It can be strapped to a wrist, ankle, shoe, or bike pedal.

## Inside the Samsung Gear Fit

# The personal trainer that helps you achieve your fitness goals



**Motherboard**
This is the brains of the operation; includes a six-axis accelerometer, gyroscope, microcontroller, processor and flash memory.

**Wireless communicators**
Combined Wi-Fi/Bluetooth/FM receiver chip and antenna exchange information with coupled smart devices.

**Inner case**
Acts as a frame to hold the rest of the goodies together.

**Touchscreen**
Curved Super AMOLED (active-matrix organic light-emitting diode) 1.84in touchscreen display with a resolution of 128 x 432 pixels.

**Wrist strap**
Interchangeable flexible plastic band comes in a variety of colours, so you can match it to your outfit or mood.

**Display**
Customisable colour display delivers alarms, emails, calls, texts and app notifications, so you can stay in the loop while you work out.

**Metal bumper**
Keeps the battery and motherboard separated.

**Battery**
Curved to fit snugly into the overall design; holds charge for up to four days.

**Unibody case**
With integrated charging connectors and square cutaway to let the heart-rate monitor "see" the skin of the wrist.

## Gesture-control armband

**Reimagining the ways you grapple with your digital world**

The Myo armband literally listens to your muscles talking. An expandable armband made up of eight muscle-sensing modules, its suite of medical-grade EMG (electromyography) sensors reads and responds to the electrical activity generated in the muscles of your forearm as you produce different gestures – including squeezing and rotating your fist, waving your hand, spreading your fingers and pointing. While it's hard to call Myo a hands-free device, it is touch-free, letting you do stuff that would otherwise involve connecting physically with controls or a computer. Its creators are connecting with developers to come up with applications from gaming and audio-video playback control, right through to sign-language interpretation and controlling lighting at concerts.

## KEY DATES
### HISTORY OF WEARABLES

**1961**
The first wearable electronic computer, used with a secret in-ear radio receiver, is invented as roulette players' cheating aid.

**1972**
Hamilton introduces the first LED digital wristwatch, the Pulsar. It has an 18-karat gold body and retails for $2,100.

**1983**
The first experimental digital hearing aid is made, comprising a behind-the-ear processor and an in-ear microphone.

**2000**
The first wireless Bluetooth headset is used as a way to speak hands-free on a mobile phone.

**2008**
The Fitbit Classic activity and sleep tracker is released, setting the benchmark for the early consumer wearables market.

**DID YOU KNOW?** *31 per cent of European businesses plan to introduce wearable tech in the workplace in 2015*

# On the horizon

**Hop aboard our time machine to see the wearables you'll be sporting in the future**

## Digital tattoos

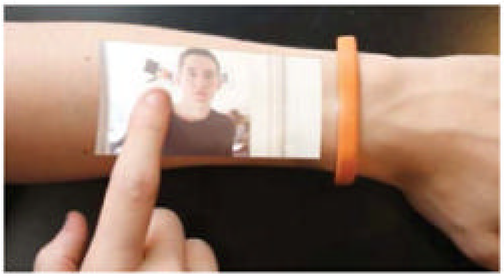
**Our first step toward cyborgdom: embedded smart tattoos**

Project Underskin – brainchild of NewDealDesign, creator of the FitBit and other wearables – is a glowing tattoo that is embedded just underneath the skin of your hand. The device is powered by your body's electrochemical energy and performs tasks in response to your hand gestures. Its capabilities include unlocking doors and exchanging data using NFC (near-field communication) signals, displaying notifications in the form of light patterns under the skin, and monitoring medical metrics such as blood-sugar levels.

## Touchscreen arms

**Finally, a display immune to fumbling, dropping and shattering**

At a first glance, the Cicret – which is pronounced "secret" – looks just like any standard fitness band, but with just one twist of your forearm, it reveals its biggest secret: a picoprojector casts an image of your smartphone's user interface directly onto your arm, turning your skin into a touchscreen! An array of eight long-range proximity sensors tracks the position of your finger as it reflects their laser output. Cicret works on all skin colours, and even works in bright daylight too.



## Microsoft HoloLens

**Experience your surroundings differently with the world's first holographic computer**

Microsoft's HoloLens is a headset with transparent holographic lenses and spatial sound, which allows you to 'pin' holograms – or virtual images – to the view of your physical surroundings. Unlike virtual reality, where you're immersed in a completely computer-generated world, HoloLens lets you experience a mixed reality, where digital aspects blend seamlessly with the physical world, and you interact with your digital content – apps, information, game elements – in the physical space around you.

## Hi-tech fashion

**Tech and couture collide in environmentally responsive catwalk pieces**

So long, little black dress. British designer Rainbow Winters produces one-of-a-kind garments whose aesthetic shifts and changes in response to environmental stimuli. Her designs include dresses made from specially dyed fabrics that change colour, glow and animate according to ambient noise, sunlight, water, UV club light and music. Winters also works with fabrics that change colour in response to stretching and twisting, as they diffract light differently under these forces.

## Google Glass looks to the future

Google Glass is an optical display visor with the functionalities of a smartphone, which you wear on your face just like a pair of standard glasses. To create Glass's display, a projector in one of its arms shines images into a small prism that protrudes into the top corner of your field of vision. The prism bends the projected light toward your eye so that when you glance at it, the image appears to hover over the physical world beyond.

Wearing Glass, you can make calls, exchange messages, get directions, surf the web, shoot photos and videos, and track your workout, all hands-free. Commands operate via blinks, voice commands and – when desired – a slim touchpad integrated into one of the device's arms.

Glass was withdrawn from the marketplace in January 2015 due to lacklustre public opinion, but Google clearly intends to develop a Glass 2, if its website is anything to go by: "The journey doesn't end here. You'll start to see future versions of Glass when they're ready (for now, no peeking)."

Glass's display is the equivalent of a 63cm (25in) HD display from 2.5m (8ft) away

© Google/ REX; dpa picture alliance/Alamy; Fitbit; iFixit; Myo; Microsoft; Cicret/Bournemouth News/REX

# Retina HD displays

## Is Apple's invention better than its counterparts?

In today's world of smartphones and tablets, a top-notch display is essential to watch the latest Vine or check out Instagram updates. Since 2010 Apple's iPads and iPhones have used a Retina display, which was considered by many to be the finest screen type on the market. After being upstaged by the likes of 4K and 1080p resolutions, it has now made a comeback in the form of Retina HD.

Apple claim that this new version of Retina fools the human eye into thinking that it is looking at a real object rather than a picture on a screen. This is due to the incredibly high pixel density, meaning the brain can't distinguish between individual pixels. At 401ppi (pixels per inch) the screen of the iPhone 6 Plus is reportedly the sharpest display available.

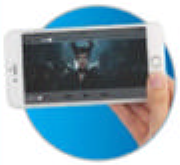
The Retina HD display also uses IPS (in-plane switching). This allows the LCD to be seen from a much wider range of angles than a regular screen. The downside to it is that the new display uses up a lot of precious battery and compatible apps take up much more of your device's space. Essentially, if an image looks better under Retina HD, it will take up a whole lot more space, for better or worse. So make sure pictures of your cats are kept to a manageable amount on your new iPhone!

Apple products that use Retina display technology produce images that are clear and crisp

## History of the Retina display

### 401 PPI iPhone 6 Plus

The first to contain a polarized layer to reduce reflections



### 326 PPI iPod Touch / iPhone 4, 4s, 5c, 5s, 6

Twisted nematic LCDs became IPS to reduce glare

### 264 PPI iPad Air

The same resolution as the iPad mini 3

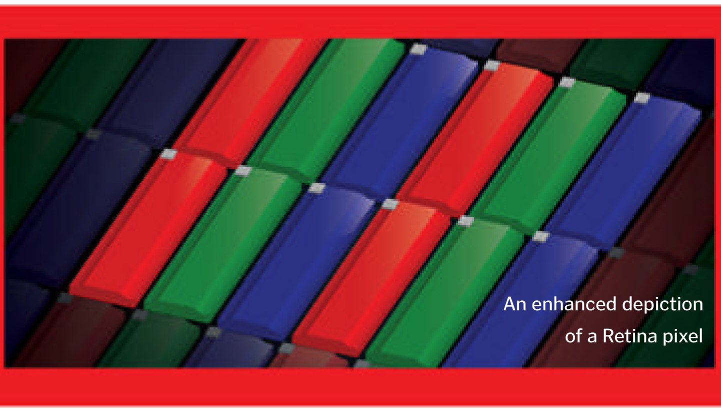
### 227 PPI MacBook Pro (3rd generation)

MacBook needs fewer PPI as it's viewed from further away

## How do pixels work?

The golden rule is the more pixels you have, the sharper the display. Pixels are made up of red, green and blue sub-pixels and signals in a device tell each when to light up. In its Retina display, Apple uses Super High Aperture (SHA) technology, which places a layer of resin between the pixels and signal lines. The pixels are so tightly packed in this system that the resin is needed to keep everything in order.

A possible downside to Retina technology is that the more pixels you squash in, the more likely they are to cause interference with each other and affect the image. SHA helps avoid this. Apple believes that a person cannot differentiate between individual pixels from one of their Retina HD devices at a normal viewing distance – around 25 centimetres (ten inches) for an iPhone and 38 centimetres (15 inches) on an iPad. It remains to be seen whether technology companies can keep pumping in pixels or whether a maximum level will be reached in the next few product generations.



An enhanced depiction of a Retina pixel

© Apple

Doppler radars can be used in a number of devices including speed guns and weather-tracking equipment (inset)

# Doppler radars

## Learn about the technology that tracks the motion of objects using echoes and the Doppler effect

Radar equipment produces electromagnetic waves, such as microwaves or radio waves. The waves hit the target and are reflected back towards the detector. In a similar way to echolocation in bats, the time it takes for the wave to reflect back can be used to determine the distance.

By sending out waves of a known frequency, the radar can also be used to determine the velocity of the target. When a police car drives past, the siren sounds high-pitched as it heads towards you, and rapidly changes to a lower pitch once it has zoomed past – this is known as the Doppler effect. If the radar target is moving towards the detector the frequency of the waves arriving at the detector is increased, and if the target is moving away, the frequency is decreased, allowing its velocity to be calculated.

Doppler radar has a variety of applications. The police use handheld radar guns to determine the speed of passing vehicles, while military planes contain pulse radars for targeting. Large-scale Doppler radar is also used to scan the atmosphere to follow aircraft, or to track and predict the weather.

# Electronic cigarettes

## How do eCigarettes create vapour that mimics tobacco smoke and are they harmful?

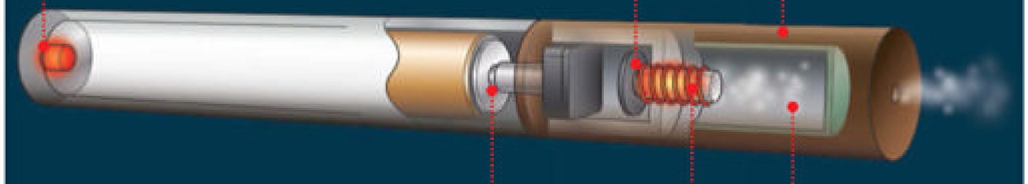
Battery-powered cigarettes convert dissolved nicotine concentrate into vapour, which can then be inhaled without many of the toxic by-products associated with burning tobacco.

The electronic cigarette has three basic components: a chamber, an atomiser and a battery. The chamber contains nicotine and flavourings in a carrier liquid, such as propylene glycol. A wick, made from metal mesh or silica, draws the liquid into the atomiser, where it is heated by a battery-powered coil until it vaporises. The vapour is then inhaled and exhaled like tobacco smoke.

Electronic cigarettes are designed to simulate the feel, taste and nicotine hit of cigarettes, but their safety is debated. In many countries their manufacture and sale is unregulated, resulting in variation in their chemical contents. Their usefulness as nicotine replacement therapy is also largely unknown and the World Health Organization does not condone their use.

### No smoke, no mirrors

**The technology that powers smoke-free eCigarettes is surprisingly simple**



**LED**
Many electronic cigarettes have a light at the end to simulate glowing embers.

**Sensor**
Some eCigarettes have a pressure sensor to detect when the user draws on the mouthpiece, powering up the coil; others use a button.

**Cartridge**
A reservoir contains the liquid and delivers it to the atomiser. A sponge is often used to hold it in place.

**Battery**
Rechargeable eCigarettes use a lithium-ion battery, which supplies power to the heating coil.

**Atomiser**
The liquid is drawn up by a wick and vaporised by a heating coil, producing a mist that resembles cigarette smoke.

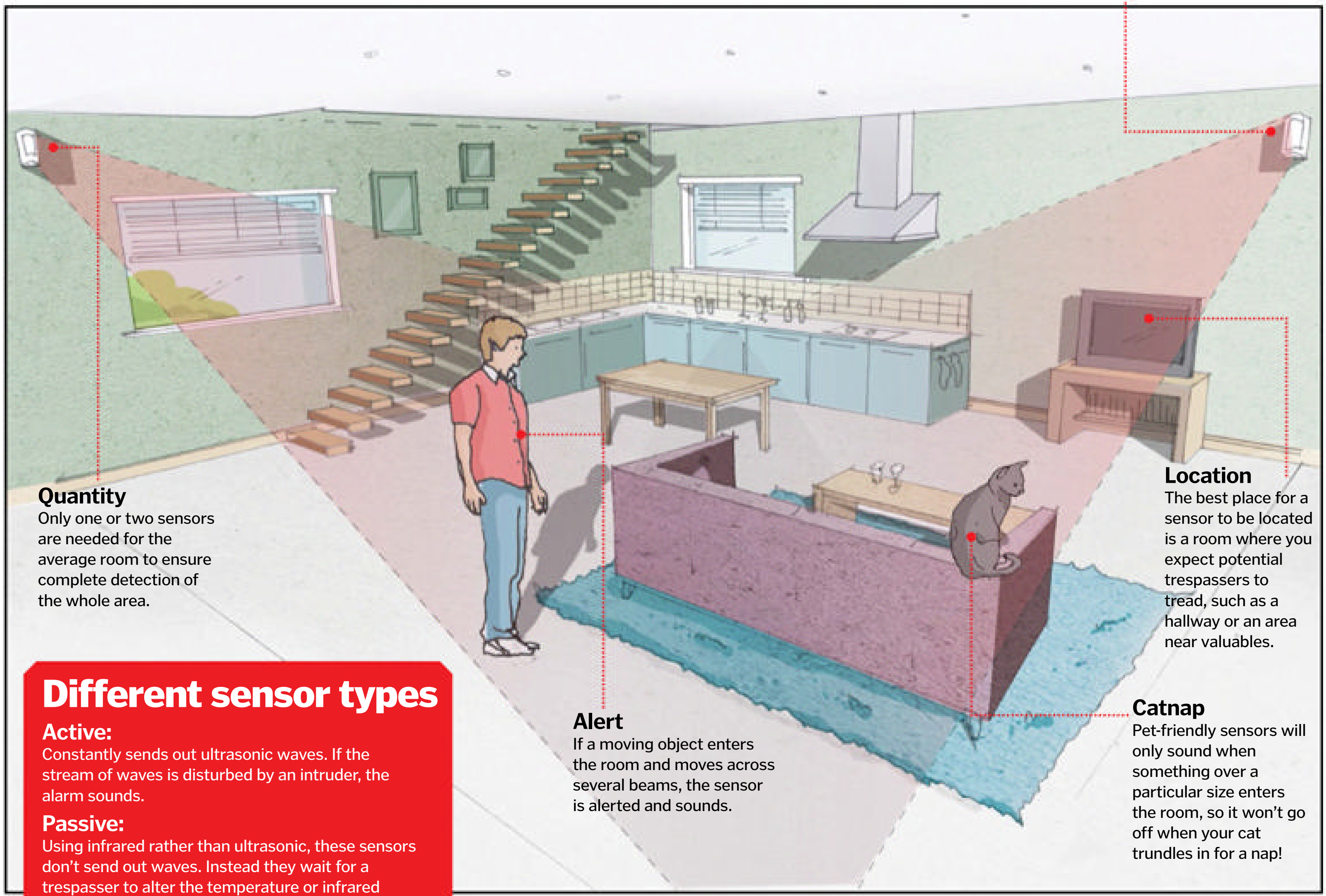
**Liquid**
Propylene glycol (PG), vegetable glycerine and/or polyethylene glycol carry the nicotine and various flavourings.

© Thinkstock

# World in motion

The inner workings of motion sensors explained

**Active and passive**
'Active' detectors use microwaves and ultrasound while infrared is the preferred wavelength in 'passive' devices.



**Quantity**
Only one or two sensors are needed for the average room to ensure complete detection of the whole area.

**Location**
The best place for a sensor to be located is a room where you expect potential trespassers to tread, such as a hallway or an area near valuables.

**Alert**
If a moving object enters the room and moves across several beams, the sensor is alerted and sounds.

**Catnap**
Pet-friendly sensors will only sound when something over a particular size enters the room, so it won't go off when your cat trundles in for a nap!

## Different sensor types

**Active:**
Constantly sends out ultrasonic waves. If the stream of waves is disturbed by an intruder, the alarm sounds.

**Passive:**
Using infrared rather than ultrasonic, these sensors don't send out waves. Instead they wait for a trespasser to alter the temperature or infrared energy of the area to make them sound.

# AR Drone 2.0

The latest generation of personal drones

Until recently, the drone world was the domain of the world's military, but now we are able to use them as our own personal moviemakers. The AR Drone 2.0 is a 380-gram (13.4-ounce) carbon-fibre video drone. Using an app you can download onto your Android or Apple device, you pilot the drone by tilting your smartphone or tablet, guided by the on-board camera.

The HD camera records at 720p, which it sends straight to the smartphone or tablet you're using to pilot the drone. If you really want to channel your inner Tarantino, you can set the drone to Director Mode. This sends it into semi-autonomous mode, providing a stable pan or crane shot. Footage remains steady thanks to a pressure sensor that keeps the drone upright regardless of altitude and winds up to 15 kilometres (nine miles) per hour.

> "At certain frequencies it acts as a sort of musak that can calm people and help prevent drunken brawls"

# Sonic weapons

Cover your ears and discover how sound can be used to stop riots and brawls

To disperse crowds and prevent rioting, various forms of non-lethal weapons (NLW) are used. Among these, interestingly, is sound. Known as an acoustic or sonic weapon, infrasound (super-low frequency) and ultrasound (super-high frequency) greatly affect human ears. They can disorientate a target and have psychological effects as well as physical effects of nausea and damage to blood vessels.

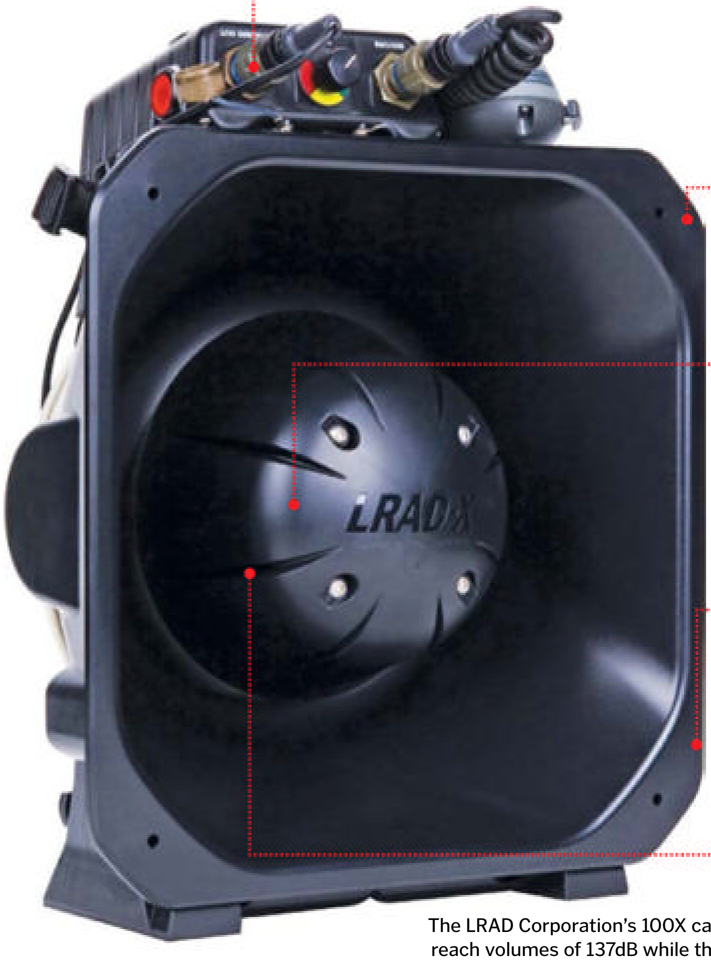
Ultrasound can be increased to 120 decibels (the same volume as a jumbo jet taking off), which is considered the human pain threshold. In contrast, infrasound feels like a damaging vibration or pressure wave, as it's at a frequency too low for humans to hear. When exposed to high levels of sound, the influx of energy has a painful effect on the body.

As well as huge decibels of volume, the variations in frequency can also cause damage. For instance, an infrasound of seven or eight Hertz can rupture blood vessels. Certain types of sound within the frequencies we are able to hear also have psychological effects, acting a sort of musak that can calm people and helps prevent drunken brawls.

In New York City, piezoelectric loudspeakers are used by the NYPD. They focus sound waves in a particular direction to control large crowds. Known as Long Range Acoustic Devices (LRAD), some types can reach a maximum of 162dB. Another device is the sonic bullet. Made by inventor Woody Norris, it sends a beam of up to 145dB into its target. Prototypes are already in production to be used in the US Army to help enforce safety areas in warzones.

## Long Range Acoustic Devices

**Discover how this breakthrough device uses sound to its advantage**



**Output**
The LRAD 100X is powered by a standard AC source or a rechargeable lithium battery. Its volume can reach up to 137dB.

**Portability**
Weighing in at a paltry 6.8kg (15lb), the 100X can easily be taken from location to location.

**Range**
Four to six times louder than all other systems of its size, the 100X has a range of over 600m (1,969ft) and can overcome background noise at 250m (820ft).

**Materials**
The 100X is made from water- and impact-resistant plastic and aluminium so it is tough enough to withstand riots and combat situations.

**Uses**
The system can be used for a variety of situations including law enforcement, border security, communication and even wildlife control.

The LRAD Corporation's 100X can reach volumes of 137dB while the 1000X can reach a hefty 153dB

© LRAD Corporation; Thinkstock; Alamy

### Perfect match

**Match the animal with the power of their sound (measured in decibels)**

218dB

110dB

230dB

Lion

Sperm whale

Tiger pistol shrimp

Answers: 218dB = tiger pistol shrimp; 110dB = lion; 230dB = sperm whale

# Digital classrooms

## From virtual lessons to interactive whiteboards, discover how new technology is revolutionising the way we learn

Technology is now at the heart of many classrooms, providing students with access to a whole new way of learning. Using digital technologies, combined with the internet, school is becoming a multimedia experience. Indeed, in 2012 there were 1.5 million iPads in use in education, as well as over 20,000 educational apps.

Of course, the internet has brought a huge resource to the digital classroom, granting instant access to a wealth of online information and educational tools. Many universities are uploading free materials to massive open online courses (or MOOCs) like iTunes U and Coursera, providing global access to free world-class education. Classrooms and labs are now also often equipped with microphones, speakers and webcams, opening up opportunities for collaborations across the globe.

Access to these digital educational resources is no longer limited to a single, rarely used computer in the corner; in fact, interactive whiteboards are now the focal point of many classrooms. A stylus, pen or finger is used to interact with a whiteboard, on which an image of the computer screen is projected. The user's movements are detected by the board and relayed back to the computer, allowing the user to write and draw on the screen (see 'Next-gen whiteboards' boxout for more detail).

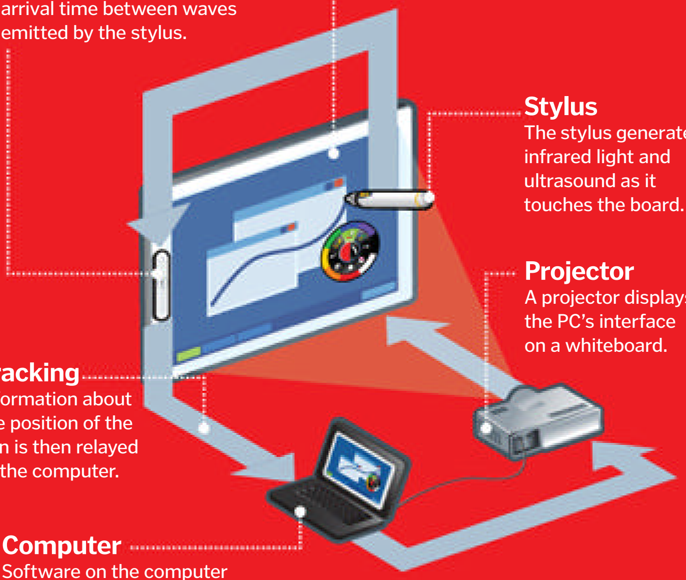
The interactive whiteboard is so much more than a digital chalkboard though. The pen-style interface means that many models come with bespoke software capable of handwriting recognition, converting everything that is written on the board into a digital archive. There are also programs available that allow anything drawn on the screen to be printed, recorded, shared and rewatched later. This has opened up possibilities for remote learning, allowing students unable to attend the physical classroom to still participate virtually.

## What technology makes a whiteboard interactive?

Interactive whiteboards use a variety of technologies to provide the interface between user and screen. Infrared whiteboards use infrared wavelengths directed across the surface of the board. When a pen touches the board, it interferes with the light, allowing the point of contact to be calculated. Similarly, ultrasound whiteboards use the deflection of ultrasound waves to detect a stylus's movements.

Some whiteboards, like the eBeam made by Luidia pictured here, do not actually need an electronic board at all, but use a detector which is mounted to the side of a traditional whiteboard.

The eBeam system actually combines both infrared and ultrasound. By using the two together, differences in the time taken for the waves of light and sound to travel across the board enable the location and direction of the pen to be pinpointed. This works in a similar way to predicting the distance of a storm based on the time delay between seeing the lightning strike and then hearing the thunder.



**Receiver**
The receiver (on the board) detects the difference in arrival time between waves emitted by the stylus.

**Infrared and ultrasound**
Light and sound travel at different speeds – by determining the time delay between each, the distance to the source can be calculated.

**Stylus**
The stylus generates infrared light and ultrasound as it touches the board.

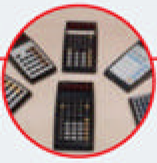
**Projector**
A projector displays the PC's interface on a whiteboard.

**Tracking**
Information about the position of the pen is then relayed to the computer.

**Computer**
Software on the computer treats the receiver as if it were a mouse, using the information to interact with the desktop.

## KEY DATES
PCs IN SCHOOL

**1970s**
Pocket calculators become affordable, with many students starting to use them to help with sums.



**1984**
There's one computer for every 92 students in the US, such as early educational PCs like the Plato.

**1991**
The first interactive whiteboard is introduced by SMART; it takes several years to go mainstream.

**2006**
Cheap, durable laptops like the XO-1 are built so kids across the developing world have access to computers.

**2010**
Many schools begin using Apple iPads for educational games, video, apps and web browsing.

**DID YOU KNOW?** *In English primary schools, there are currently around 1.8 students to every computer*

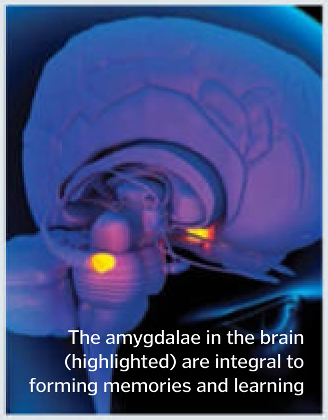
Dusty chalk and squeaky pens are now very much things of the past

## How do we learn digitally?

As we learn, connections between neurons in the brain are reinforced; the more they are used, the stronger they become and the more easily we are able to recall the information.

Digital classrooms provide an engaging environment to reinforce memory. Different people find that they learn more easily in some ways than others – some preferring to watch, others preferring to interact, etc. Digital classrooms are able to offer tailored ways of learning, appealing to a wide range of preferences, and enabling classes to be adapted to individual students. One of the major advantages is that technology makes learning more fun, keeping pupils engaged for longer and providing memorable experiences to really help the knowledge stick.

One technique being increasingly employed to enhance learning through technology is 'gamification' – essentially turning learning into a game. The best educational games allow the student to learn without even realising it. Many of these games also include virtual rewards and leaderboards for an extra incentive.


The amygdalae in the brain (highlighted) are integral to forming memories and learning

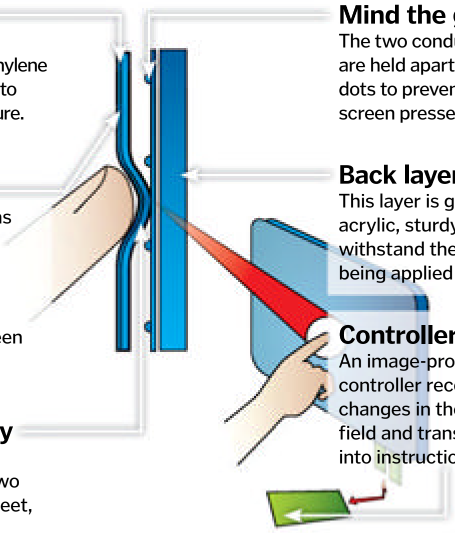
© eBeam; SPL; Mike McGregor

# Touchscreen interaction

This tactile technology comes in two main flavours – resistive and capacitive – but what are the key differences between them?

## Resistive screen

**Tougher, cheaper and simpler, resistive touchscreens are widely used in our everyday devices**



### Top layer

This is typically made of scratch-resistant polyethylene (PET) which is designed to flex slightly under pressure.

### Resistance

Resistive touchscreens are made of several layers, each with a conductive indium tin oxide (ITO) coating. A current passed between these layers creates electrical resistance.

### Push technology

When pressed with a finger or stylus, the two ITO coatings below meet, completing a circuit.

### Mind the gap

The two conductive layers are held apart by spacer dots to prevent accidental screen presses.

### Back layer

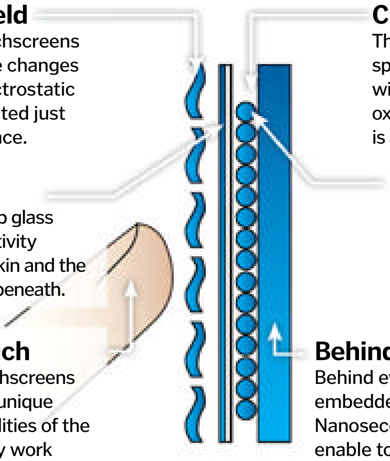
This layer is glass or acrylic, sturdy enough to withstand the pressure being applied at the front.

### Controller

An image-processing controller recognises changes in the electrical field and translates these into instructions.

## Capacitive screen

**More accurate and much more versatile capacitive has to be today's touchscreen of choice**



### Invisible field

Capacitive touchscreens monitor minute changes in the local electrostatic field being created just above the surface.

### Glass layer

Touching the top glass creates conductivity between your skin and the charged space beneath.

### Human touch

Capacitive touchscreens respond to the unique conductive qualities of the skin. They rarely work with gloves (unless special capacitive ones).

### Charged space

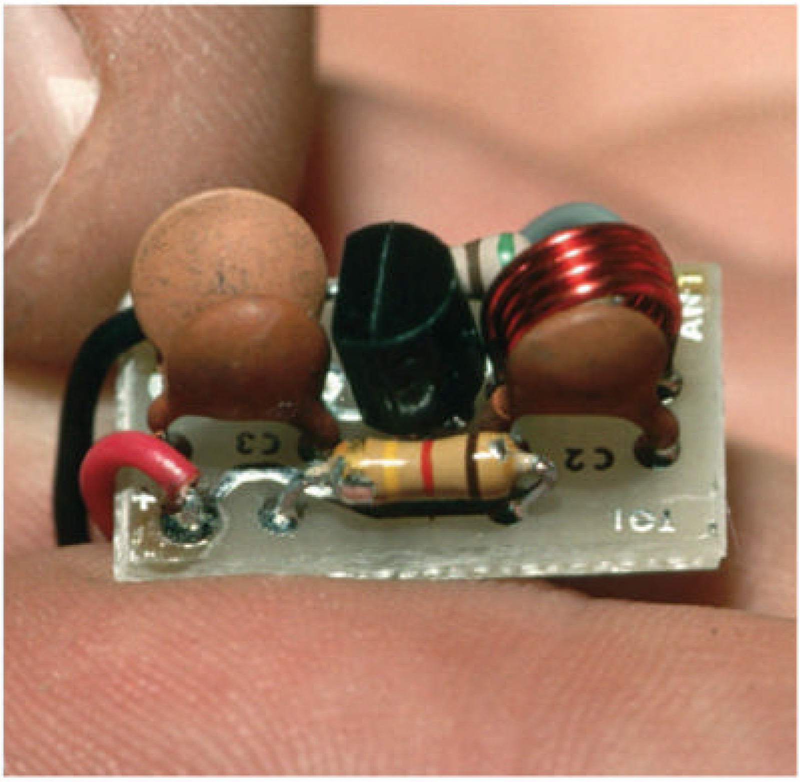
The screens are made up of spaced layers of glass coated with a fine film of indium tin oxide (ITO). A minute charge is applied to this space.

### On the grid

Some touchscreens use technology where one layer is etched with a grid pattern of electrodes for even greater precision.

### Behind the screens

Behind every electrode lies an embedded microcontroller. Nanosecond response times enable today's smartphones and tablets to interact almost instantly to our touch.



# Phone bugs explained

Learn how modern listening devices eavesdrop on our conversations

Traditionally bugs have two main components: a microphone to capture the audio and a radio transmitter to relay the conversation to the listener. The microphone is activated when sound reaches a threshold level, or when a radio signal of the correct frequency is sent to the device.

Newer bugging techniques tend to take advantage of modern mobile phone and laser technology. GSM (Global System for Mobile Communications) audio bugs contain a SIM card. When called, the bug will automatically – and silently – answer, and pass on audio to the listener's phone. Laser listening devices, on the other hand, do not require a microphone at all, but detect the changes in vibration of objects as sound waves hit them. A laser aimed at a particular reflective surface, like a window, can detect minute changes in the vibration caused by shifts in air pressure as people talk. Laser bugs require the listener to be in line of sight of the target, but unlike microphone-based devices, no one needs to break into a property to plant the bug.

© Corbis

# Electron guns

## Far from a weapon, these guns are an important part of everyday electricals

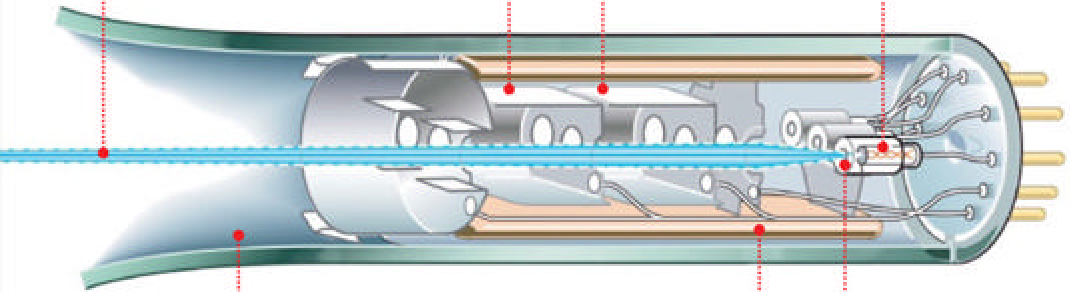
Electron guns are a very versatile electrical component. They are essential to a number of devices, from 3D printers and welders to the large synchrotron at the Diamond Light Source in the UK and the electric systems of Kimball Physics in the US. But how do they work? It's all down to kinetic energy and electrical currents. When installed in an electrical device's vacuum tube, the gun turns electrons and ions into usable beams of energy by releasing them from their metal source (cathode). This process is known as thermionic emission.

Inside the gun there is a small filament that heats the cathode, which makes it release a stream of electrons. The electrons accelerate rapidly and the resulting beam is pulled toward the neighbouring anode, which is positively charged. There are small holes in the anode which allow some electrons to pass through, so a concentrated beam then continues onward within the device. JJ Thomson discovered the electron using this concept in 1897 after conducting experiments with cathode rays and studying their uses.

There are two main types of electron gun: thermionic and field emission. The former are much more common and work at a high temperature. Field emissions have less heat but a higher brightness and electric field. Additionally, 'flood guns' are used to scatter the beam over a wider area.

## Naked gun

**Inside the inner workings of an electron gun**



**Electron beam**
Now a strong and usable ray of light, the electron beam can exit the gun to work in the rest of the device.

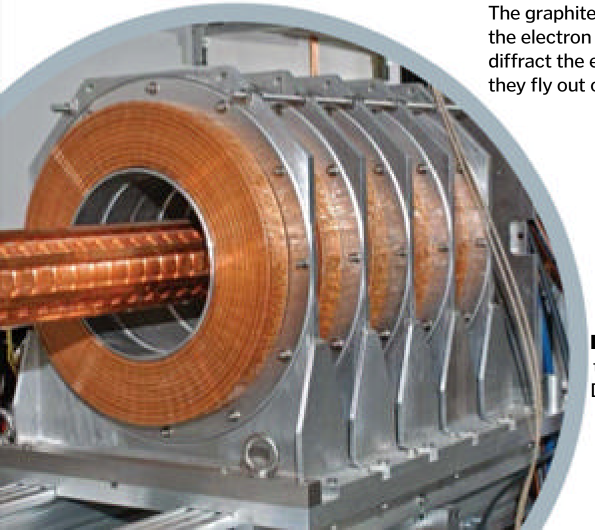
**Anode**
Made up of two parts, the anodes accelerate and focus the electrons to make a beam.

**Heater**
Working in unison with the cathode, the heater's hot filament begins the whole electron-gun process.

**Graphite**
The graphite foil coating of the electron gun helps diffract the electrons as they fly out of the gun.

**Cathode**
Warmed by the heater, this is where the electrons are heated and emitted.

**Insulator**
An insulator is provided within the gun to be used as a charge drainage path for excess energy.



**LEFT** The electron gun at the Diamond Synchrotron in Didcot, Oxfordshire

**Learn more**
For more on electron guns, check out the Diamond Light Source website at **www.diamond.ac.uk**

Chris Christou working on the Diamond Light Accelerator

## Electron expert

**We chat to Chris Christou, the head of the radio frequency group at Diamond Light Source, who have a supremely powerful electron gun of their own**

### How is energy turned into a usable product by the gun?

The key is getting the electrons out of the conductor, which the electrons are bound to. The hard part is controlling the electrons once they have escaped. We heat the metal, which gets the electrons out of the cathode and then pulls them away with a high electric field.

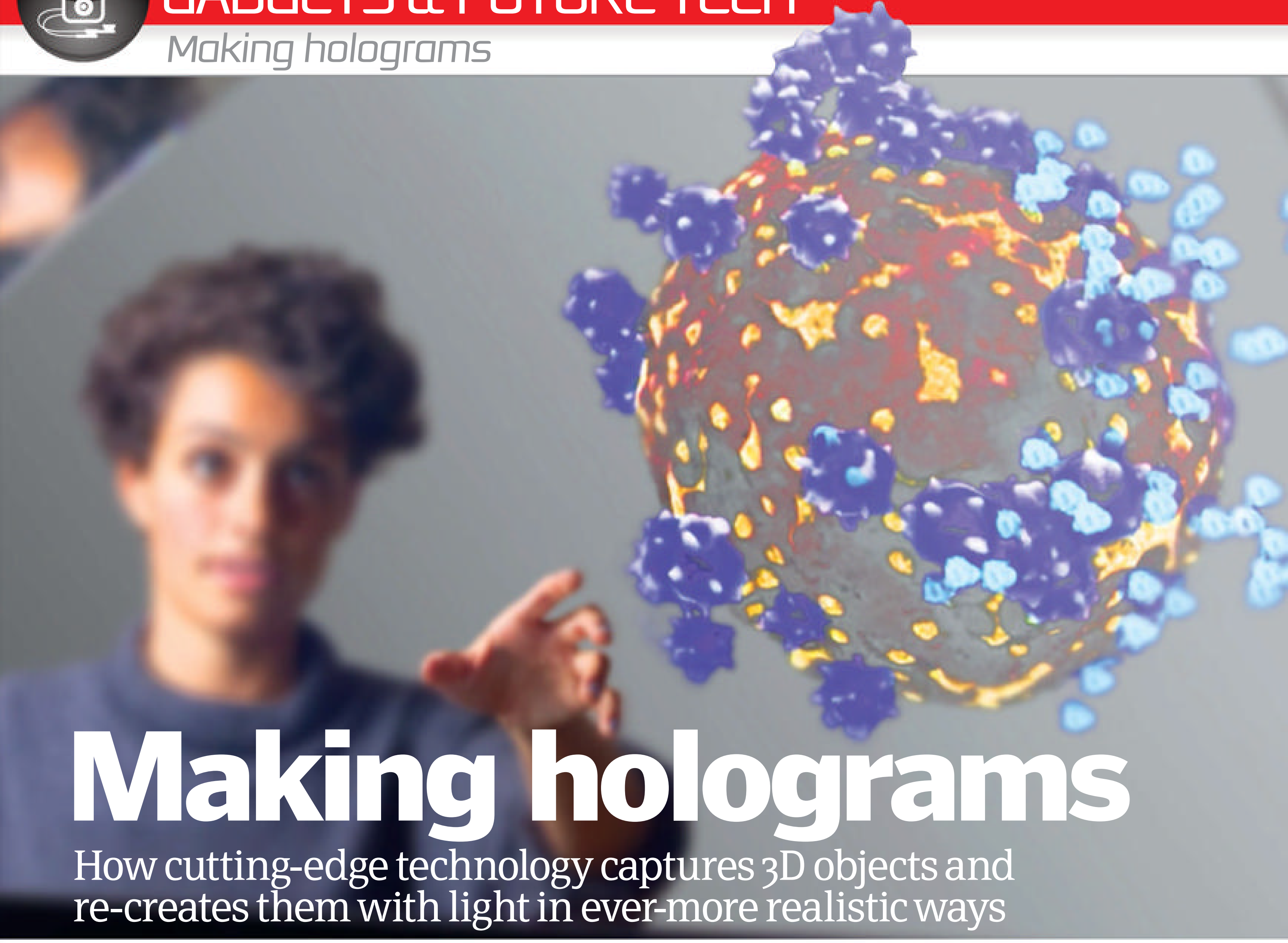
### How do they work in TVs and the Diamond synchrotron? These are very different things!

Electron guns are very versatile as the physics behind them is relatively simple. It's just giving energy to an electron to take it away from a bound state. The hard part is controlling the beam after it comes out of the cathode of the gun. At Diamond we have a set of electrodes on the gun, which shape the beam to allow it to be extracted and taken into the linac. Old cathode-ray TVs have something like 10,000 volts to accelerate the beam straight into the screen. So the difference between TVs and us is what we do with the beam is after it's been generated.

### Where would industry be without the invention of an electron gun?

Until recently you'd have had no TV sets, but that wouldn't matter, because you'd have nothing to watch, as radio/TV transmitters use an amplifier with an electron gun. It's not just TV, though; old-fashioned electrical valves were based on electron beams and so we would have missed an essential step in the development of electronics.

©Getty; Diamond Light Source



# Making holograms

## How cutting-edge technology captures 3D objects and re-creates them with light in ever-more realistic ways

The principle of making a hologram is similar to recording an orchestra in surround sound – once the sound has been recorded, the orchestra can stop playing and the sound can be re-created again and again without any instruments.

Instead of recording audio, a hologram stores the interference pattern generated by light scattered by an object. This allows that light scatter to be reproduced later, giving the illusion the object is still there.

Capturing a hologram requires a laser light source – most often a red helium-neon laser. The light is divided by a beam splitter and each new beam travels a separate path to the holographic recording plate. The first beam – the object beam – travels to the object itself, while the second goes to a recording plate as a reference to obtain the interference pattern.

Before they reach their targets, each beam travels through a lens. Unlike the lens of a camera, the lenses of a holographic recorder are not designed to focus light, but instead spread it out. As the object beam strikes the object, light is reflected and refracted, some of it in the direction of the holographic recording plate. As the object beam reaches the plate, it collides with the reference beam, generating an interference pattern. Interference is recorded using fine grains of photosensitive chemicals, similar to those used in photography.

In essence, the exposed holographic plate is more like a CD than a photographic negative. The stored information cannot be deciphered with the naked eye, instead appearing as a series of bumps and wavy lines. In order to actually view a hologram, a light source must be applied to the film.

There are two main types of hologram, with each viewed in a different way. To look at a transmission hologram, a monochromatic light is passed through the film, producing a floating three-dimensional image of a single colour (most often green). Alternatively, reflection holograms, like those found on bank notes, bounce back light and can be multicoloured.

The process of creating a hologram is incredibly light-sensitive, much like traditional photography, so holographic recording is done in a darkroom. Due to the red colour of most holography lasers, traditional red darkroom lights damage the holographic plates, so green or blue-green lights are used instead.

Holography is also much more sensitive to environmental conditions than photography; so much information is packed into such a small space that even minute deviations in the lasers can ruin the hologram. Vibrations in the floor, in the air from body movement or even as people breathe can disrupt the delicate recording process.

Despite the difficulties in creating holograms, the storage capacity they provide is quite

## 5 TOP FACTS
### HOLLYWOOD HOLOS

**Iron Man**
**1** In the live action *Iron Man* films, starring Robert Downey Jr, eccentric entrepreneur Tony Stark uses holographic projection to manipulate three-dimensional prototypes.

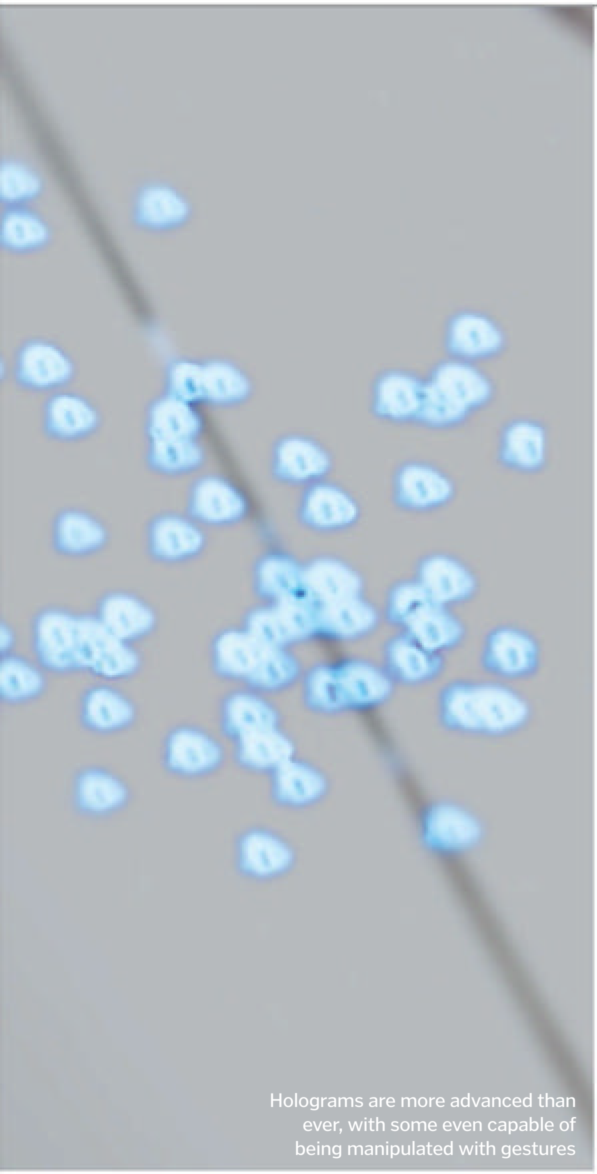
**Star Wars**
**2** In the *Star Wars* universe, holography is used as a form of video communication. They are monochrome and visible from all sides, much like real holograms existing today.

**Minority Report**
**3** In Steven Spielberg's 2002 thriller, Tom Cruise controls a holographic heads-up display using motion sensors on his gloved hands to help prevent future crimes.

**Vanilla Sky**
**4** A holographic projection of jazz musician John Coltrane appears in the apartment of Tom Cruise during one scene of the 2001 futuristic drama *Vanilla Sky.*

**Back To The Future Pt II**
**5** This 1989 film predicted that by 2015, holographic displays would be used to advertise films like *Jaws 19.* Now in 2014, a similar real-life display advertised *Captain America 2.*

**DID YOU KNOW?** Some physicists hypothesise that our universe is actually a hologram, while the 'true' universe is two-dimensional


Holograms are more advanced than ever, with some even capable of being manipulated with gestures

simply incredible. Holographic images are truly three-dimensional and can be viewed from all angles. The images are also scalable and holograms made with one wavelength can be viewed with another – the size of the resulting hologram scaling with the wavelength of viewing light. In theory, this means that holograms of extremely small structures, down to the molecular scale, could be created using X-rays and then viewed using visible light, although this is yet to be done.

One of the major challenges in holography is producing moving holograms - much like camera film, when conventional holographic recording plates are exposed, the image is fixed. Scottish company Holoxica has developed a holographic screen capable of storing prerecorded holographic images. The screen is illuminated from behind, generating a holographic projection above. The screen can switch between the prerecorded images to

## Waking the dead

In 2012, the audience at music festival Coachella were surprised and amazed when the rappers Snoop Dogg and Dr Dre were joined on stage by the musician Tupac Shakur, who died in 1996.

Using a combination of video footage, CGI, body doubles and motion capture technology, it is now possible to digitally resurrect deceased performers, and bring them back to the stage. This illusion was created using the Musion Eyeliner, and we spoke to Liz Berry, director at Hologramica, about how these incredible illusions are produced and projected.

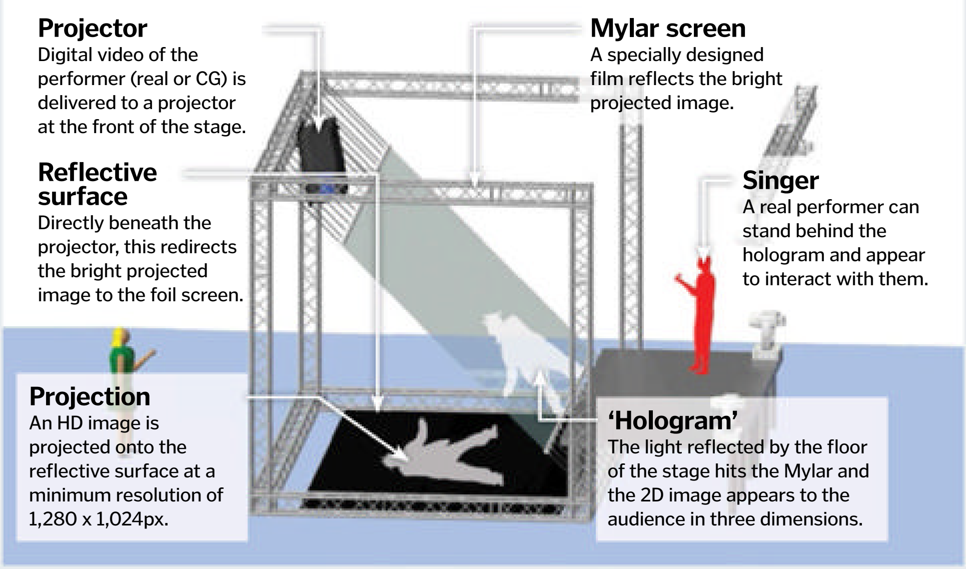
"You need a continuous full body shot of the subject(s) being projected as HD video. This can be achieved by doing a film shoot, or you may be lucky and find existing footage for someone you can't film. Alternatively you can use CGI. Sometimes it's a mix. So, for example, Frank Sinatra was created with both old footage and new film, using CGI to combine the two as a lifelike hologram.

"Every element of the presentation has to feel authentic. The lighting has to be right, and that's the single most important factor. But for me it has to start with the design of the stage itself to give you the most effective and elegant way of deploying physically bulky equipment that has to be placed accurately. Some considerations are purely technical, others are creative and take a good image and enhance it by finding ways to blend the real and the virtual seamlessly."

Thanks to hologram technology, deceased rapper Tupac was able to grace the stage once more

## Digital resurrection tech

**Using a 21st-century version of a Victorian theatre trick, singers can perform to millions from beyond the grave**


**Projector**
Digital video of the performer (real or CG) is delivered to a projector at the front of the stage.

**Reflective surface**
Directly beneath the projector, this redirects the bright projected image to the foil screen.

**Projection**
An HD image is projected onto the reflective surface at a minimum resolution of 1,280 x 1,024px.

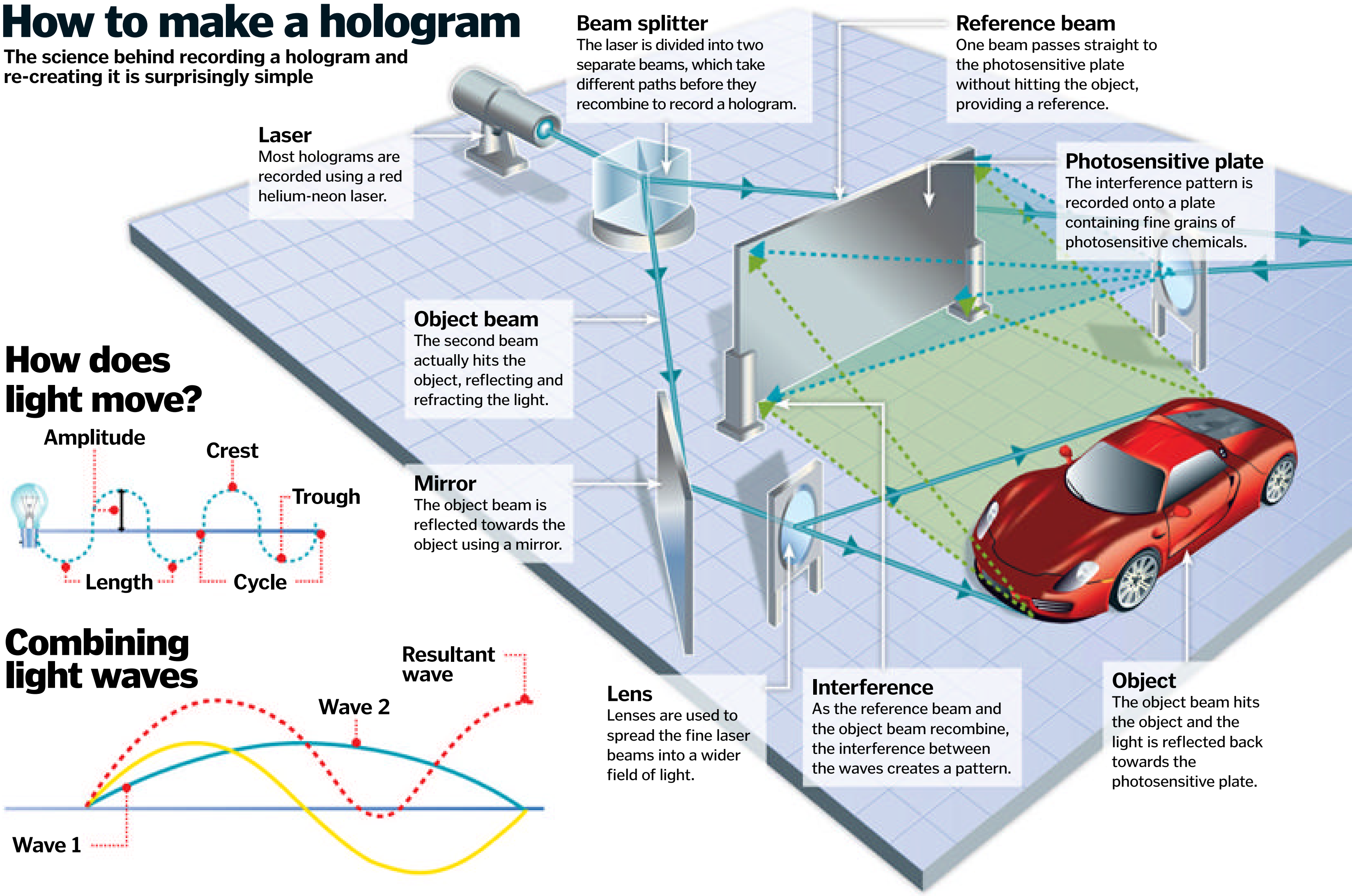
**Mylar screen**
A specially designed film reflects the bright projected image.

**Singer**
A real performer can stand behind the hologram and appear to interact with them.

**'Hologram'**
The light reflected by the floor of the stage hits the Mylar and the 2D image appears to the audience in three dimensions.

# How to make a hologram

**The science behind recording a hologram and re-creating it is surprisingly simple**



**Laser**
Most holograms are recorded using a red helium-neon laser.

**Beam splitter**
The laser is divided into two separate beams, which take different paths before they recombine to record a hologram.

**Reference beam**
One beam passes straight to the photosensitive plate without hitting the object, providing a reference.

**Photosensitive plate**
The interference pattern is recorded onto a plate containing fine grains of photosensitive chemicals.

**Object beam**
The second beam actually hits the object, reflecting and refracting the light.

**Mirror**
The object beam is reflected towards the object using a mirror.

**Lens**
Lenses are used to spread the fine laser beams into a wider field of light.

**Interference**
As the reference beam and the object beam recombine, the interference between the waves creates a pattern.

**Object**
The object beam hits the object and the light is reflected back towards the photosensitive plate.

## How does light move?

## Combining light waves

change the visible projection. By using collections of simpler interference patterns more complex images can be created, a bit like pixels forming an image on an LCD screen.

True moving holograms might not be here yet, but companies like Musion, AV Concepts and Hologramica are using advanced digital media techniques to create realistic, life-size 3D projections that are the next best thing. Between them, they have given form to the animated band Gorillaz, staged a piano battle between a musician and his holographic double, and even brought musicians back from the dead (see the 'Waking the dead' boxout).

We spoke to Liz Berry, the director of 3D holographic projection company Hologramica, about the secret behind these incredible stage shows – an old illusion known as Pepper's Ghost: "Pepper's Ghost was originally used in Victorian theatres to make supernatural effects. They would place a lit performer out of the audience's view and position a piece of glass between the performer and the audience. The viewers wouldn't know they were viewing the stage through the angled glass because it's transparent, and the lit actor's reflection would appear as a ghostly apparition. The modern take uses bright HD video and the glass is now a specially developed foil. The image is projected onto a concealed screen on the floor so you only see the reflection in the foil, and voila!

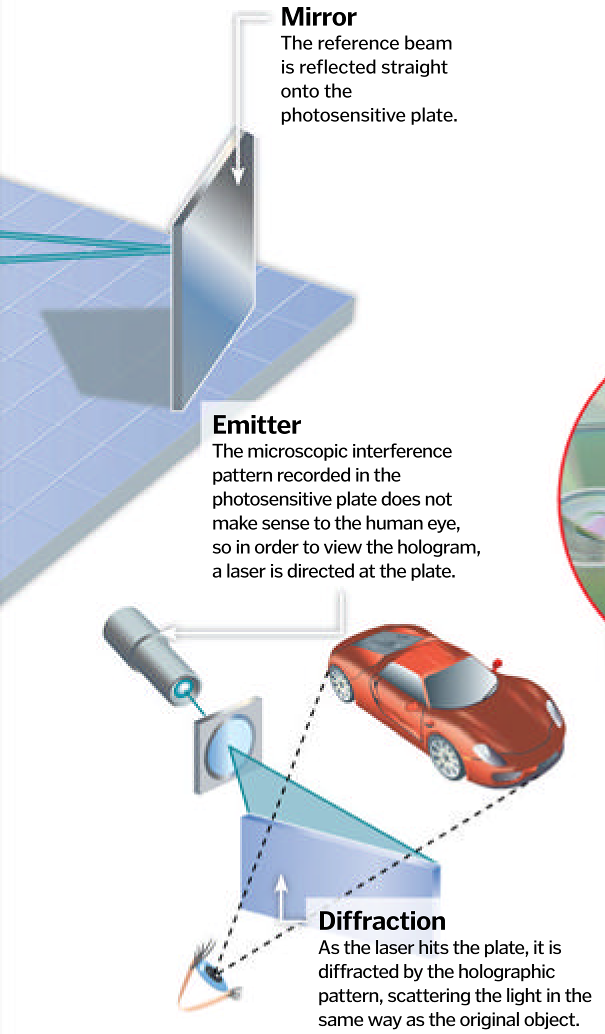
"So the holographic illusion is basically HD video in 2D. Although what we create isn't technically a hologram in the truest sense, it's become popularly known as that. I sometimes think we should run a competition to come up with a better name, but I guess we have to stick with hologram for now!"

This tech has been miniaturised by British company Beagle Media, which has developed one of the most advanced hologram players – Holo. Using a Mac Mini and four 140-centimetre (55-inch) Samsung panels, a 2D image is projected to appear in three dimensions. Not only that, but motion sensors allow the object to be manipulated in real-time with gestures.

Illusion techniques are also being used to explore the development of touchable holograms. The mirage toy is a classic illusion; an object is placed on top of a concave mirror, and a second mirror is placed on top. The reflection of the light inside the mirrored chamber focuses the image just above an opening at the top, making it appear as though the object is sitting outside of it.

Researchers at the University of Tokyo are using it as a tool to develop holograms we can interact with. Hand movements are tracked using infrared sensors from Nintendo Wii remotes, while airborne ultrasound signals create tiny pressure waves that mimic the sensation of touch. Microsoft is developing similar technology with Kinect.

**DID YOU KNOW?** *Leia Display Systems take advantage of light scattering to create 3D projections on sheets of water vapour*



**Mirror**
The reference beam is reflected straight onto the photosensitive plate.

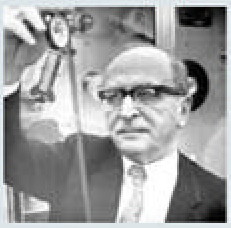
**Emitter**
The microscopic interference pattern recorded in the photosensitive plate does not make sense to the human eye, so in order to view the hologram, a laser is directed at the plate.

**Diffraction**
As the laser hits the plate, it is diffracted by the holographic pattern, scattering the light in the same way as the original object.

The potential for these kinds of technology is vast. Not only can holographic images be used for entertainment, art and education, but the potential applications in medical science, technology design and augmented reality are huge. Doctors in Israel are already using interactive holograms to help perform surgery by re-creating real-time models of organs during operations, while research at the Human Media Lab at Queen's University in Ontario, Canada, is at the early stages of designing a 3D version of Skype (pictured right).

True moving holograms might currently look like LCD screens from the 1980s, but look at where those screens are now. For Hologramica, it's all about achieving the impossible: "[We can] make cars float, turn ballerinas into crystal swans, and do things on stage that you can't do by any other means; people engage emotionally with these images as well as just looking at them. Seeing is believing."

## The man behind the hologram



Hungarian-British engineer Dennis Gabor was awarded the Nobel Prize for Physics in 1971 for the invention of the holographic method. He realised that optical imaging only records the amplitude of waves, not the phase, and that if you recorded both, a three-dimensional image could be captured. Despite conceiving his initial ideas in 1947, the laser was not invented until 1960 and it was not until 1964 that the first hologram was made.

### 5 reasons why holograms beat CDs hands down

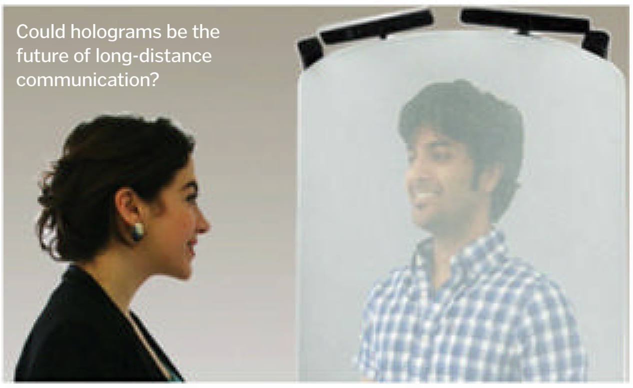
- ✓ Higher storage capacity
- ✓ Faster data transfer
- ✓ Long-term stability
- ✓ Unaffected by magnetic fields
- ✓ Smaller size

## The future of data storage

Holograms aren't just useful for displaying 3D images in art galleries and at music festivals; they could also be the next big thing in data storage.

Conventional storage methods, like CDs and DVDs, can only store information in two dimensions, can only be accessed from one angle, and must be read in series as the disk spins. By representing binary information visually, as clear and black boxes, it is possible to store it in hologram form. A 3D storage hologram could be read, and written to, from all angles, and different areas could be accessed in parallel, allowing compact storage and superfast replay.

A demonstration of the Airborne Ultrasound Tactile Display which enables us to touch holograms, developed at University of Tokyo



Could holograms be the future of long-distance communication?

## Everyday holograms

### 1 Security hologram

Perhaps the most widely recognised and are used to mark items like credit cards, bank notes and passports. The images are hard to replicate and are used to prevent counterfeiting and fraud.

### 2 Museum archiving

Holographic records of museum artefacts not only enable them to be shared worldwide, but they also allow curators to monitor any deterioration in the condition of their collection. It also serves as evidence in case an item is lost or stolen.

### 3 Medical imaging

Instead of viewing a simulated 3D image on a screen, doctors are finding it increasingly useful to convert digital images taken by medical scanners, including MRI and ultrasound, into holograms.

### 4 Barcode scanners

Holographic scanners use laser beams to explore barcodes. Each beam follows a different path, generating a three-dimensional image of the barcode, allowing it to be read from any direction, even if the scanner is facing the side of the packet.

### 5 Heads-up display

Holographic HUDs effectively superimpose a navigational display onto a pilot's view out of the cockpit. Advances in hologram technology will soon enable HUDs to be incorporated into the glass of car mirrors too.

© Alamy; AV Concepts; Beagle Media; Corbis; Shinoda Lab, University of Tokyo; Human Media Lab, Queen's University; Ian Moores Graphics

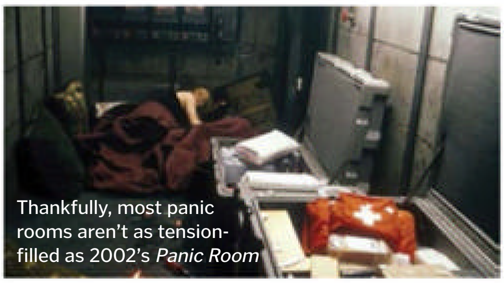
# How panic rooms work

What goes into the ultimate home defence unit?

Panic rooms hit the spotlight in 2002 when Jodie Foster and Kristen Stewart starred in a film where they were trapped in one, but what are these modern-day boltholes and how are they constructed?

A panic room is a safe place for occupants of a property to go whenever they feel threatened. The danger could be in the form of an intruder or a natural threat like an earthquake or hurricane. These rooms are typically windowless for maximum security and the only weak point of these rooms might be the door, but to combat this, panic room doors are constructed from super-thick steel, have reinforced frames and are fitted with high-level security locks. Fingerprint scanners or keycode entry pads provide an extra barrier, and sometimes the door is so well concealed that a trespasser may not even know the room exists.

The room must provide all the essentials for staying alive during a potential long-term situation, so basic plumbing, air filtration and a good stock of medical kit, food and water are all standard. The most expensive panic rooms might also feature monitors hooked up to a CCTV system to keep an eye on intruders' movements as well as a means of communication to contact the outside world.


Thankfully, most panic rooms aren't as tension-filled as 2002's *Panic Room*

## A game of hide and seek

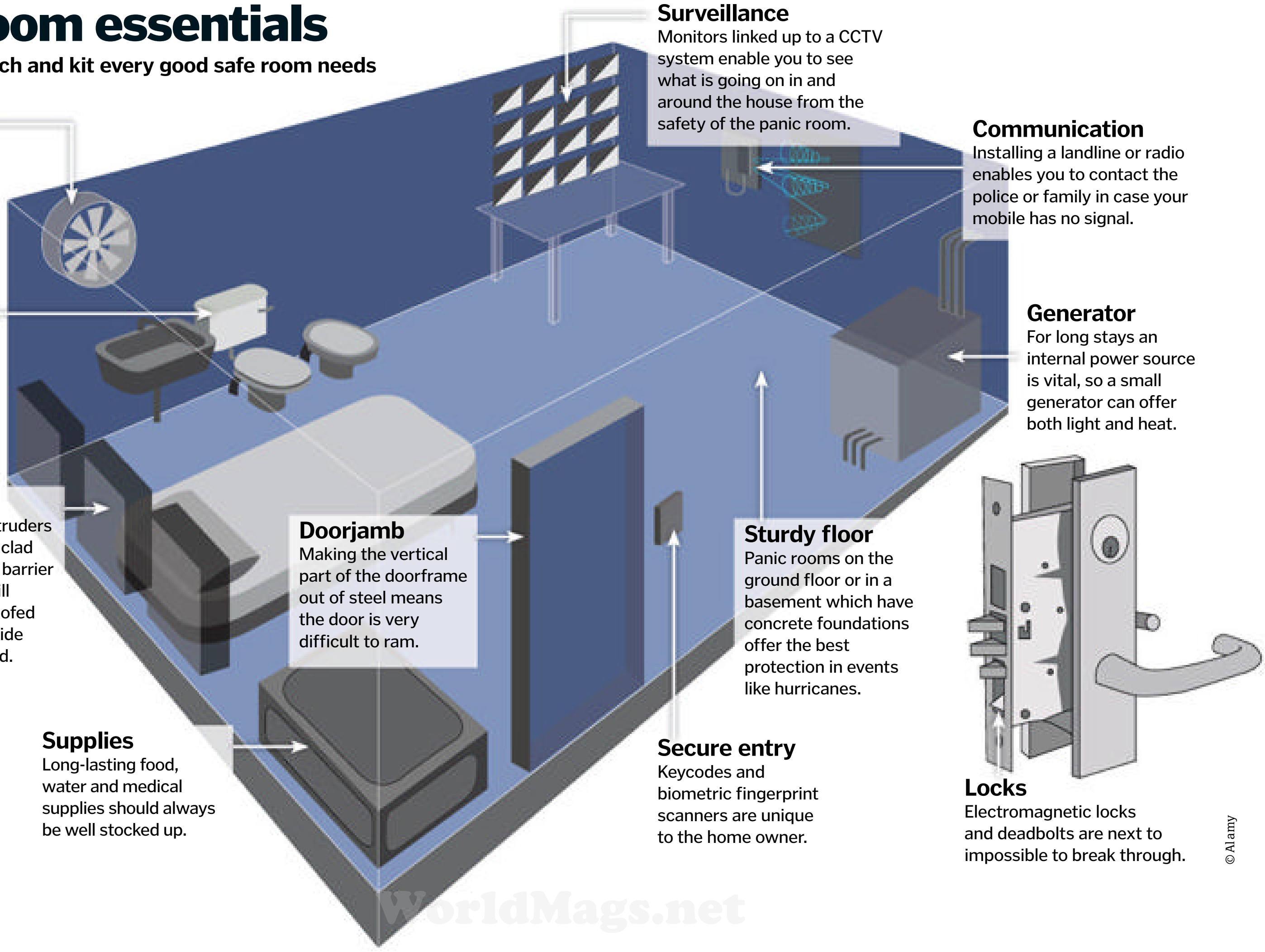
People who are designing custom-built panic rooms to evade intruders are constantly coming up with new and more ingenious ways of keeping these hideaways, well, hidden.

While secret rooms behind bookcases may seem more in line with Enid Blyton fiction than real life, the fact is that a hidden entrance to a panic room could prevent assailants even knowing you're in the building, making it the ultimate defence.

There are examples of panic room doors hidden behind sliding walls, underneath floorboards or through the back of a closet. To ensure a panic room is as well hidden as possible, companies are offering tailor-made services, creating precisely constructed moving walls, which can barely be seen without prior knowledge. Although these are very costly, the peace of mind that comes with increased safety often takes precedence.

## Panic room essentials

**Explore the key tech and kit every good safe room needs**



**Air filtration**
If you're going to be in an enclosed environment for a while, a system for circulating fresh air is a must.

**Plumbing**
Nature will inevitably call if stuck in the room for some time, so a toilet is a must and a sink provides essential water.

**Kevlar walls**
If there's a risk that intruders may be armed, Kevlar-clad walls provide an extra barrier of protection. Walls will generally be soundproofed too so you can talk inside without being detected.

**Supplies**
Long-lasting food, water and medical supplies should always be well stocked up.

**Doorjamb**
Making the vertical part of the doorframe out of steel means the door is very difficult to ram.

**Surveillance**
Monitors linked up to a CCTV system enable you to see what is going on in and around the house from the safety of the panic room.

**Communication**
Installing a landline or radio enables you to contact the police or family in case your mobile has no signal.

**Generator**
For long stays an internal power source is vital, so a small generator can offer both light and heat.

**Sturdy floor**
Panic rooms on the ground floor or in a basement which have concrete foundations offer the best protection in events like hurricanes.

**Secure entry**
Keycodes and biometric fingerprint scanners are unique to the home owner.

**Locks**
Electromagnetic locks and deadbolts are next to impossible to break through.

© Alamy

**RECORD BREAKERS**
**ROWING FEAT**

# 6 HUNDRED

**MOST ROWERS IN 24 HOURS**

On 8 March 2013, 600 people rowed 500m (1,640ft) each in 24 hours at Mercyhurst University in Pennsylvania, USA.

**DID YOU KNOW?** Sir Steve Redgrave produced up to 500W during his Olympics races, enough to power a PC for six hours

# Gore-Tex

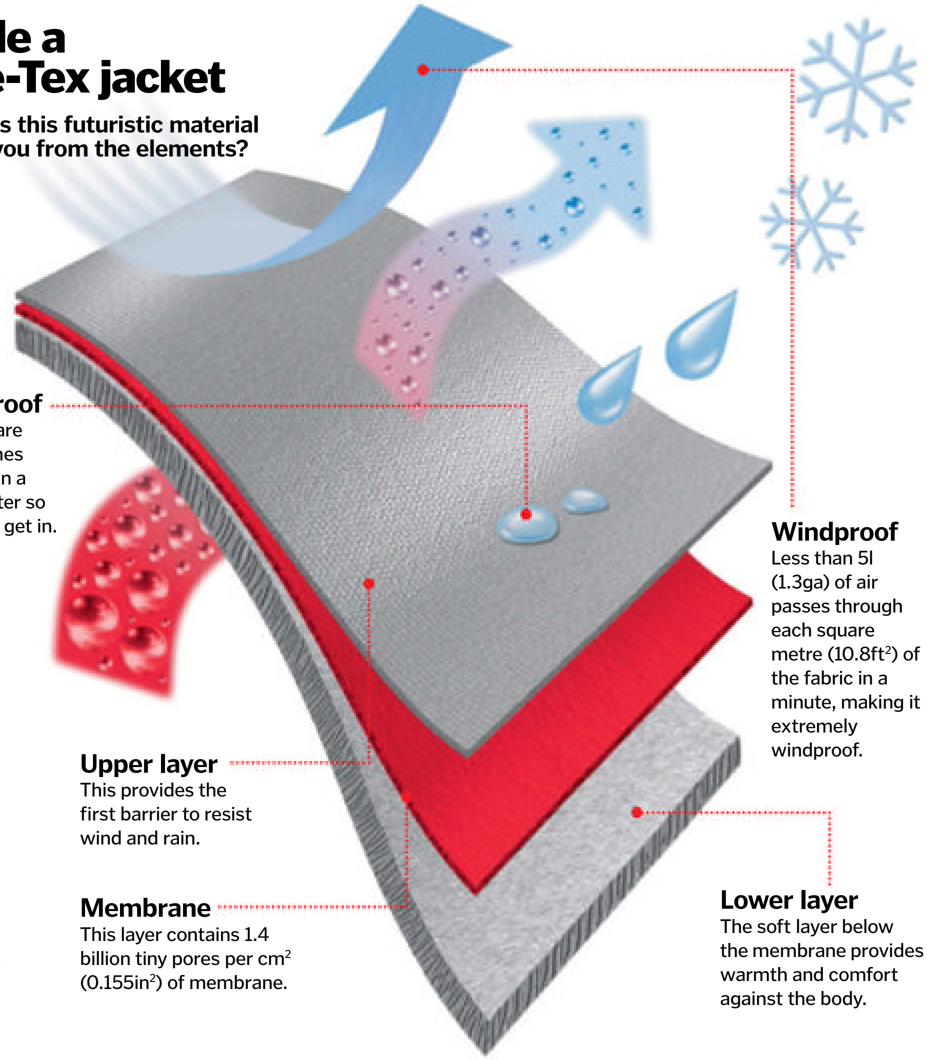
## The science behind this waterproof and windproof material

Gore-Tex clothing is a favourite among hikers because it keeps Mother Nature at bay. Unlike nylon – which is waterproof but traps sweat – Gore-Tex is a 'breathable' fabric. It has all to do with a thin membrane embedded in the garment where there are 1.4 billion pores per square centimetre (0.155 square inches). As each pore is larger than a water vapour molecule, sweat is able to escape through the fabric. These tiny pores also massively reduce the amount of wind that can get in.

This doesn't stop it being waterproof, however. Even though each pore is bigger than a water vapour molecule, it is smaller than a liquid water molecule, so rain is unable to get through to your body.

### Inside a Gore-Tex jacket

**How does this futuristic material protect you from the elements?**



**Waterproof**
The pores are 20,000 times smaller than a drop of water so no rain can get in.

**Windproof**
Less than 5l (1.3ga) of air passes through each square metre (10.8ft$^2$) of the fabric in a minute, making it extremely windproof.

**Upper layer**
This provides the first barrier to resist wind and rain.

**Membrane**
This layer contains 1.4 billion tiny pores per cm$^2$ (0.155in$^2$) of membrane.

**Lower layer**
The soft layer below the membrane provides warmth and comfort against the body.

# How rowing machines work

## The first step to becoming the new Sir Steve Redgrave

Rowing machines are a staple of the gym, but how do they work and what does that lever on the side actually do? The entire system of indoor rowing works on the principle of resistance. When you pull the chain back it spins a flywheel inside the housing. As you return to the starting position the chain winds back round, ready for another tug on the flywheel.

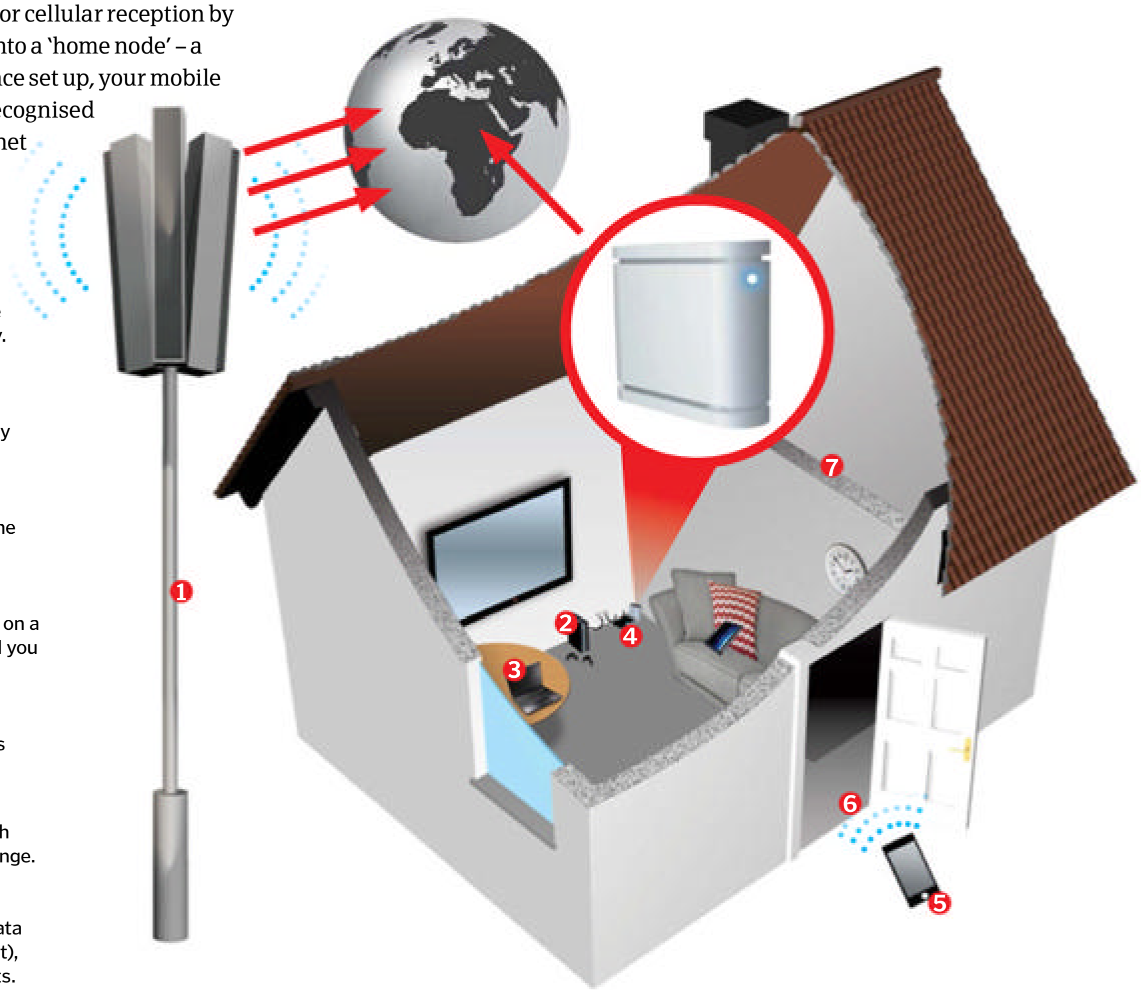
The lever on the side is called the damper and this affects how much air is allowed into the system. When the setting is higher, more air is able to get in, making the flywheel harder to rotate as it's battling against more air resistance. Even when you're on the return stroke, the air is still working against you, slowing the flywheel down so it takes more effort to pull it back again.

© Thinkstock; Mountain Equipment GTX; Gore

# Home nodes explained

Find out why femtocells are perfect if you live in a signal black spot

Femtocells can be the solution to poor cellular reception by turning your broadband landline into a 'home node' – a mini mobile phone base station. Once set up, your mobile phone and other gadgets are automatically recognised and any voice calls use VoIP (Voice over Internet Protocol) data packets to connect a call. Unlike Wi-Fi, femtocells don't drain your devices' battery life either.



① **Cell tower**
Rather than relying on overcrowded cell towers in the area, the femtocell interacts with the internet directly.

② **No interference**
An operator-licensed spectrum is used which means there should be no interference from other technology around the home, like video consoles.

③ **Home network**
The femtocell automatically syncs your device with the wider home network for easy media sharing.

④ **Modem**
The femtocell is plugged into a spare Ethernet socket on a modem. Input your phone number via a webpage and you can start using all the usual mobile phone services.

⑤ **Improved calls**
As the femtocell is taking over voice calls, many users experience improved levels of call clarity.

⑥ **Instant recognition**
You can connect many devices to the femtocell, which are automatically recognised when they come into range.

⑦ **Boosted signal**
The femtocell increases the speed and reliability of data transmission, extending the range to about 30m (98ft), improving signal in homes with thick walls/basements.

# Duplicating keys

Discover how the unique notches and grooves are added to fit bespoke locks

Key-cutting machines create exact copies by tracing the design of the original key onto the new one

Simple locks have keys based on a series of larger teeth, so many locks can tolerate some inaccuracy, and manual key-cutting machine is still used in duplication. The original is clamped on top of the new key, forming a template. The operator then traces the outline with a cutting blade, producing a duplicate pattern in the new key.

A skilled operator can make nearly identical keys, but it's very time-consuming, and high-security locks require greater precision. Automated key-cutting machines are more accurate. These use the same principle as the original is used as a template, but the keys are clamped separately. A stylus traces the outline of the original and the machine transfers it to the copy using a cutting blade. For higher-security keys, a laser-cutting device is used, allowing for extremely high precision. This technique introduces tiny pits into the surface, increasing the lock's complexity.

Some keys are not copied at all. So-called 'code keys' use a predefined map stored on a memory device. In order to replicate these, you just need the code, containing instructions for the locations and dimensions of the grooves.

© Peters & Zabransky; Thinkstock

**DID YOU KNOW?** *Today some advanced skyscrapers even have self-cleaning, window-washing robots*

# How are skyscraper windows cleaned?

## Discover how the tallest buildings on the planet keep up appearances

There are three main factors involved when it comes to cleaning skyscraper windows: cleaning equipment, cleaning mechanism technology and environmental considerations.

Due to the epic heights and natural factors like wind involved in the operation, every cleaner is equipped with a harness, descent and safety rope, rope protector, rope-grabbing tool, descent mechanism, lanyard and suction cups. Together these tools enable the worker to negotiate a building's vertical façade at speed, while attached to a roof-mounted anchor. This anchor allows cleaners to descend in 'drops' – the measurement of one vertical cleaning operation from roof to the below floor or platform – without fear of falling.

When group work is necessary, a cleaning mechanism will be employed (see boxout on the right for more information). These mechanical gantries enable teams of cleaners to work in unison and are powered by roof-mounted hydraulic and pneumatic support systems. The ascending and descending of the gantries is dictated by a control panel, but as a backup additional control systems are typically placed on the roof of the building.

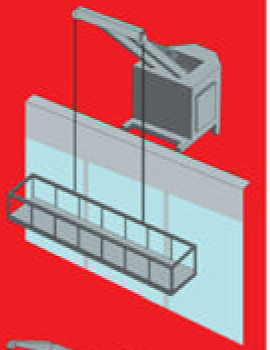
Lastly, when cleaning skyscraper windows, workers must constantly be vigilant of potentially deadly environmental factors – the chief one being wind. At the high altitude of skyscrapers, wind flow is not just fierce but highly turbulent, with the building acting as a disrupter to the general environmental flow. These gusts can blow cleaners off course, cause tools to be dropped (risking anyone passing below) and render gantries unusable. Luckily, many modern skyscrapers – such as the world's tallest, the Burj Khalifa in Dubai – are now being designed to smoothly redirect winds around their structures and prevent the buildup of vortices and turbulence.

A head for heights is a must for any skyscraper window cleaner!

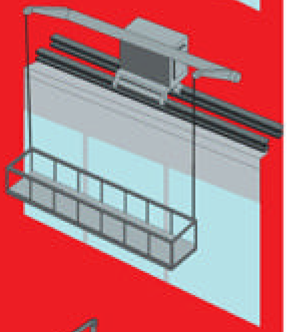
## High-altitude window cleaning

### Here are four of the most common skyscraper cleaning mechanisms

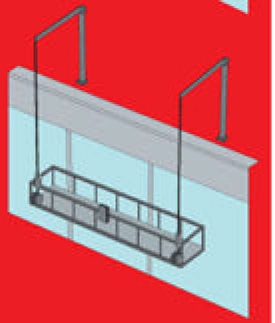
**Boom**
One of the most popular cleaning systems historically, the boom lets a building's façade be accessed easily by a large team. The boom system is permanent and can be operated on-gantry or off.



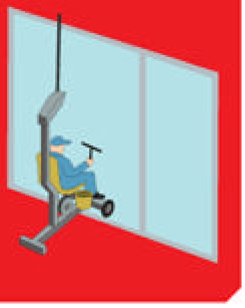
**Carriage**
These rail-mounted carriages enable gantries to cover larger areas of a building's façade due to their ability to move left and right. As with booms, they are permanent structures and cannot be moved around the building.



**Portable davit**
The cheapest and simplest solution for cleaning skyscraper windows, portable davits move between fixed bases on a roof, enabling access to different sides of the edifice with just one davit-based system.



**Bosun's chair**
A more modern development in skyscraper window cleaning technology, the bosun's chair gives a single cleaner access to a tall building's windows from a safe seated position. They are ideal for tight areas and use over long periods.



© Dreamstime

# Terrariums explained

Discover how these fish tank-like devices are used to grow tropical plants

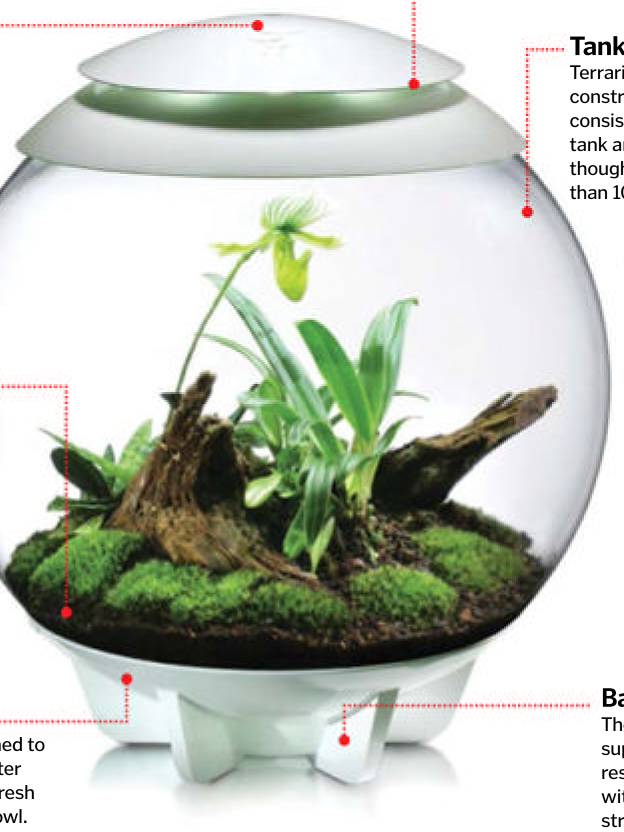
Terrariums are a special type of enclosure with a glass case that specialise in re-creating a foreign habitat that is very different to the room they are located in. Typically they are used to grow plants that can only exist in tropical climates, such as croton or selaginella, with a series of lighting, water and circulation systems artificially imitating their native habitat.

Animals can be kept in terrariums too, with turtles being one of the most common inhabitants. However, their prime modus operandi is for botanical or decorative purposes, akin to a fish tank in modern homes and offices. It's worth noting, as can be seen in the 'Get to know your habitats' boxout at the bottom of the page, terrariums differ from other similar enclosures like insectariums and formicariums.

Indeed, a terrarium's focus on plants and flowers makes it in many ways more akin to a botanical garden's tropical glasshouse than an aquarium, with facilities like the Eden Project in the UK and the Biosphere 2 in Arizona sharing much of its technology, albeit on a far larger and more complex scale. For a closer look at the key components that make up a modern domestic terrarium, check out the main image.

## Anatomy of a terrarium

**What technology enables us to re-create tropical forests within a small glass sphere?**



**Lighting**
A series of LED lights is mounted within the lid to replicate necessary levels of illumination and heat for the plants to grow effectively.

**Misting module**
To ensure that the artificial water cycle of the terrarium is well distributed, a misting module in installed.

**Tank**
Terrarium tanks are similar in construction to aquariums, consisting of a base, glass tank and lid. Sizes vary, though most are no more than 100cm (39.3in) tall.

**Planting tray**
The compost for the terrarium's plants is placed on top of a special capillary mat that draws water from the system's reserves while preventing saturation.

**Fans**
A fan network attached to an internal carbon filter ensures a supply of fresh air throughout the bowl.

**Base**
The terrarium's power supply, fans and water reservoir are located within the base. Support struts extend from the base to maintain stability on flat surfaces.

## Get to know your habitats…

**Aquarium**
An aquarium is a simulation of a water habitat, like a river or lake. It can be fresh or salt water and contains marine creatures.

**Insectarium**
An insectarium is a special type of simulated dry habitat that caters solely to insects and arachnids such as the tarantula.

**Vivarium**
Similar to a terrarium, albeit designed more for animals, vivariums are typically home to a wide variety of flora and reptiles.

**Paludarium**
An artificial habitat that re-creates swamp or rainforest habitats. It features aspects of both aquariums and terrariums.

**Formicarium**
Similar to the insectarium, the formicarium is an artificial habitat that re-creates conditions for ant colonies.

**Riparium**
A riparium is a very particular type of paludarium – one in which the contained water sources have a circulating current.

© Reef One; Steve Jurvetson

## 5 TOP FACTS
### POOL OF FABRICS

**Cotton**
1 The most basic of the costumes, cotton swimsuits aren't the strongest or the most hydrodynamic but they are usually the most comfortable to wear.

**Nylon**
2 Nylon is the most commonly used material for swimwear due to its light weight and strength, but struggles in the Sun's rays where it can fade, and it also frays over time.

**Polyester**
3 Polyester is strong and comfortable but its range of merits pales in comparison to nylon so polyester is primarily used in other types of clothing rather than swimsuits.

**Spandex**
4 Most commonly known as Lycra, spandex boasts excellent elasticity. It is often used with other fabrics as it doesn't hold up well to chlorine and can be itchy.

**Polyurethane**
5 The pantomime villain of swimsuit materials as it has been banned in competitions. The material enclosed tiny pockets of gas that made swimmers more buoyant.

**DID YOU KNOW?** *The world's most expensive bikini is made entirely of diamonds and is worth an estimated £18mn ($30mn)!*

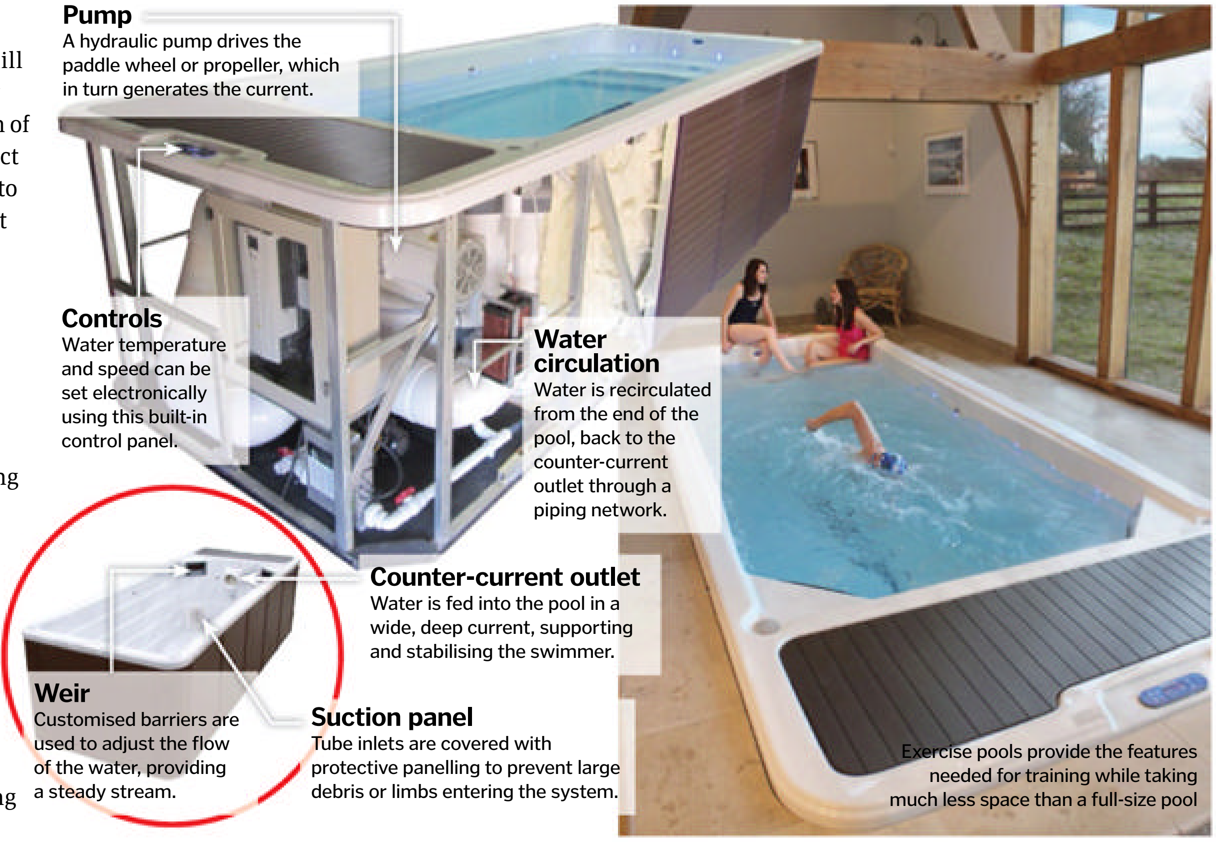
# How exercise pools work

## Inside the domestic swimming machines that let us swim for miles on the spot

Exercise pools are the equivalent of a treadmill for swimmers. Usually only measuring twice the length of an average person, these compact training pools allow swimmers to practise, using a counter-current system to provide a continuous flow of water to swim against.

Water is pumped using a propeller or paddle wheel and enters the pool at the front end. The speed of the current is adjustable and the water is pumped at low pressure, entering the pool in a wide stream. This minimises the bubbles and turbulence associated with the kind of jet used in Jacuzzis.

Tubes running from the back end of the pool carry water around the outside and return it to the pump, allowing the swimmer to train without the need for a full-size swimming pool or a wave machine.



**Pump**
A hydraulic pump drives the paddle wheel or propeller, which in turn generates the current.

**Controls**
Water temperature and speed can be set electronically using this built-in control panel.

**Water circulation**
Water is recirculated from the end of the pool, back to the counter-current outlet through a piping network.

**Counter-current outlet**
Water is fed into the pool in a wide, deep current, supporting and stabilising the swimmer.

**Weir**
Customised barriers are used to adjust the flow of the water, providing a steady stream.

**Suction panel**
Tube inlets are covered with protective panelling to prevent large debris or limbs entering the system.

Exercise pools provide the features needed for training while taking much less space than a full-size pool

# Why racing swimsuits make us faster

## The streamlined fabrics and designs making waves in competitive swimming

Although they may look simple, swimsuits have been engineered to help swimmers glide through the water.

Most important is the hydrodynamic shape. New materials are designed to reduce drag and compress the body into its most streamlined form, helping to reduce lactic acid buildup in the muscles. The fabrics can be made from nylon or spandex and are designed to be lightweight and have a high compression-to-weight ratio. Bonded seams, for instance, reduce drag by six percent compared to sewn seams.

Suits made of hydrophobic (water-resistant) microfilament textiles can reduce drag by eight per cent. They work by effectively pushing the water away from a swimmer's body.

All these measures help swimmers get ever quicker. So quick in fact, that in 2010, polyurethane suits were banned from competitive swimming as they gave an unfair advantage after records tumbled at the 2009 World Swimming Championships.

Comfort for the swimmers is also a priority of course. Special widened straps help avoid soreness while wide-vision goggles aid sight and reduce drag. Even harmful chemicals are combated with new materials resisting chlorine up to ten times longer than older suits.

Swimsuits have become a hi-tech aid to competitive swimmers in recent years

© Speedo; Corbis

# Growing plants without soil

Hydroponic systems already grow tomatoes and lettuce, and might one day produce new superfuels

Hydroponics is a system of growing crops in nutrient-enriched liquid baths rather than soil. Normally, roots anchor the plant in the ground and absorb all the water, minerals and nutrients from the soil the plant needs in order to grow. They cannot break down the soil particles but rely on the dissolved solution between them.

Hydroponics does away with soil and grows plants with their roots suspended in an aerated nutrient solution in greenhouses. The roots can also be supported in an inert medium, like gravel or sand, and flooded with a fertiliser solution. Tomatoes, cucumbers and peppers grown hydroponically in greenhouses in American deserts produce five to ten times as much crop weight per year as those grown in irrigated, open fields. Worldwide, hydroponic greenhouses now cover an area equivalent to 17,500 football fields and produce crops worth £3.5-4.7 billion ($6-8 billion) a year.

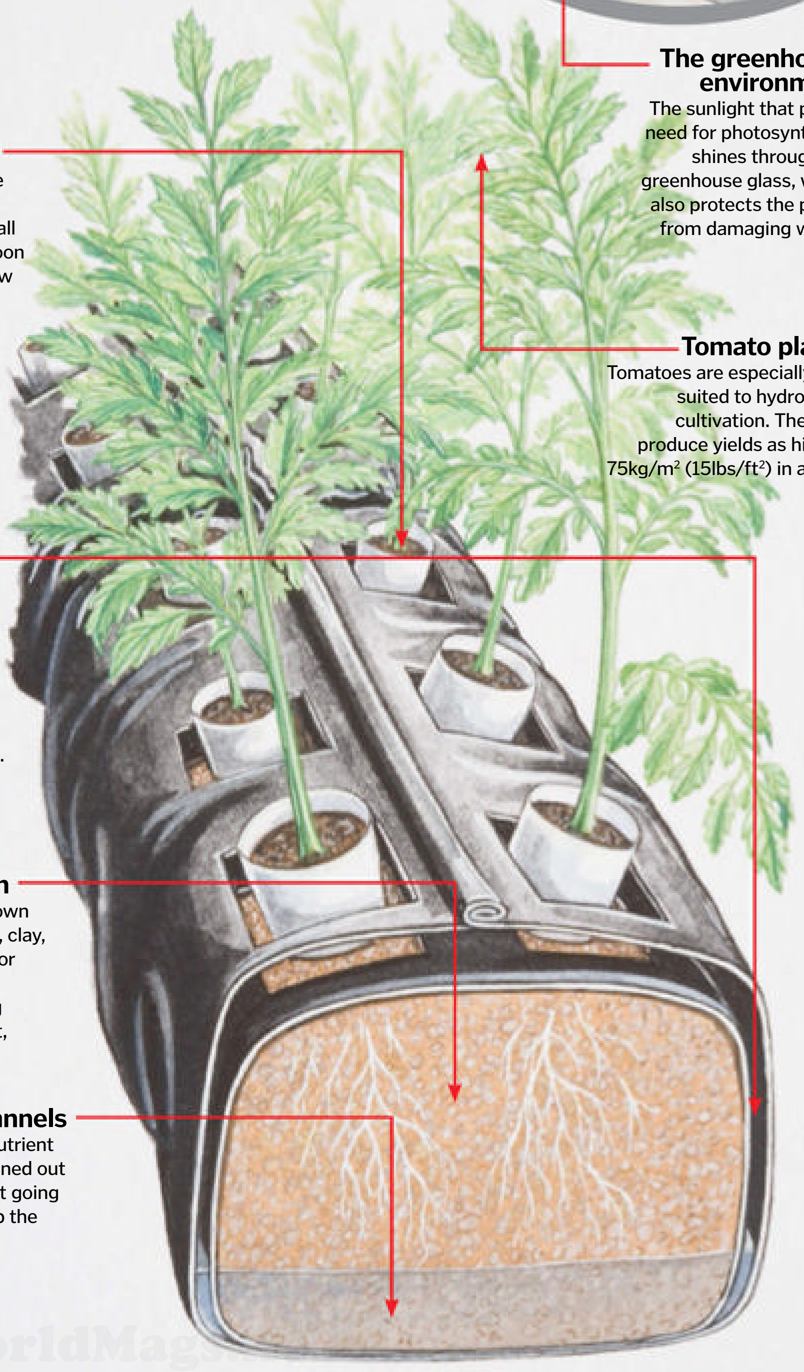
A new use is being developed for hydroponics. Algae (simpler plants) are grown in tanks in the sunshine, absorbing CO$_2$ from the atmosphere. They develop 20 times as fast as traditional crops, so a portion can be harvested daily. This is fermented to produce ethanol and the mush left behind is buried. This process locks up carbon dioxide, helping to reduce greenhouse gases that cause climate change.

## Growth spurt

- THE IDEAL CONDITIONS FOR GROWTH
- RAINWATER IS AN IDEAL SOURCE
- 25°C [77°F]: OPTIMUM TEMPERATURE
- PLENTY OF OXYGEN IS NEEDED
- FRESH NUTRIENTS EVERY WEEK
- PH LEVELS SHOULD BE BETWEEN 5 AND 6

## The greenhouse effect

**How does a typical hydroponic system work?**



**Starter pots**
In this system, the seedlings are germinated in small pots of soil, but soon their roots outgrow these pots.

**The greenhouse environment**
The sunlight that plants need for photosynthesis shines through the greenhouse glass, which also protects the plants from damaging winds.

**Tomato plants**
Tomatoes are especially well suited to hydroponic cultivation. They can produce yields as high as 75kg/m$^2$ (15lbs/ft$^2$) in a year.

**Nutrient bath**
A balanced solution of nutrients in water is poured into the inert medium to nourish the tomatoes' growth.

**Inert medium**
The roots grow down through rockwool, clay, vermiculite, sand or gravel – an inert medium providing structural support, not nourishment.

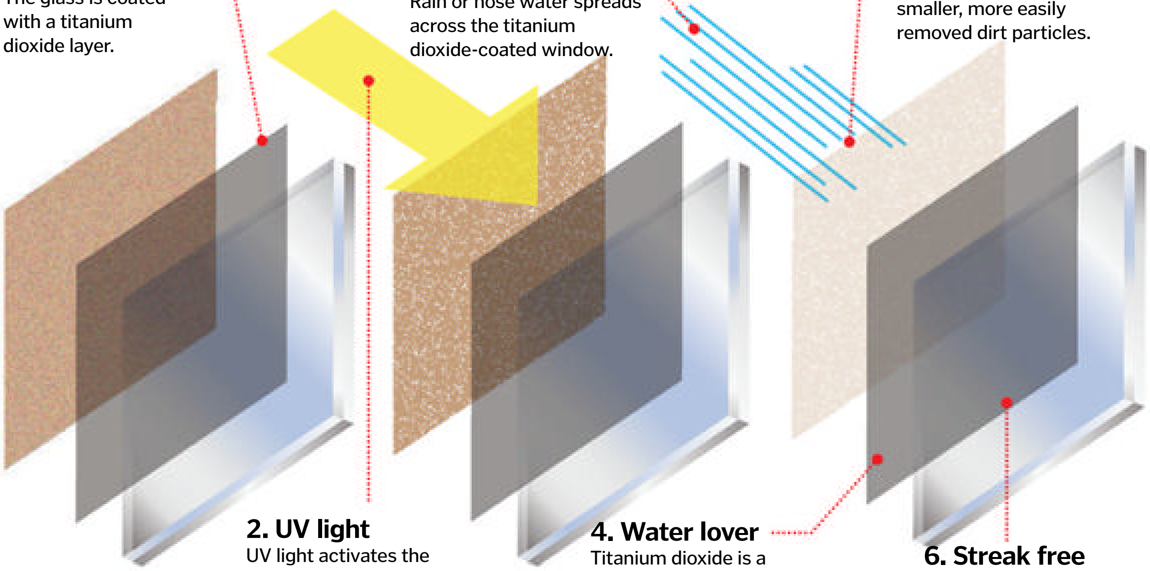
**Drainage channels**
These allow the nutrient solution to be drained out regularly, to stop it going stagnant and keep the roots oxygenated.

WorldMags

# Self-cleaning glass explained

## The technology that could spell the end for window cleaners

Cleaning windows can be an absolute chore, especially if they are high up. Luckily, a new invention on the market could mean the days of chamois leather, a bucket and a ladder are reduced to a distant memory. Glass is coated with a chemical compound of titanium dioxide that is activated by UV light. This compound reacts with dirt, breaking it down into tiny particles. This makes it much easier for the dirt to be washed off with just a quick blast of a hose. Even ordinary rain is enough to work away the smaller, looser dirt particles. This is because of the compound being hydrophilic, making water spread all over the surface, rather than streak down in droplets.



**1. The coating**
The glass is coated with a titanium dioxide layer.

**2. UV light**
UV light activates the layer which reacts with dirt, breaking it up into much smaller pieces.

**3. Rainy day**
Rain or hose water spreads across the titanium dioxide-coated window.

**4. Water lover**
Titanium dioxide is a hydrophilic substance, which means water wants to cover as much of it as possible.

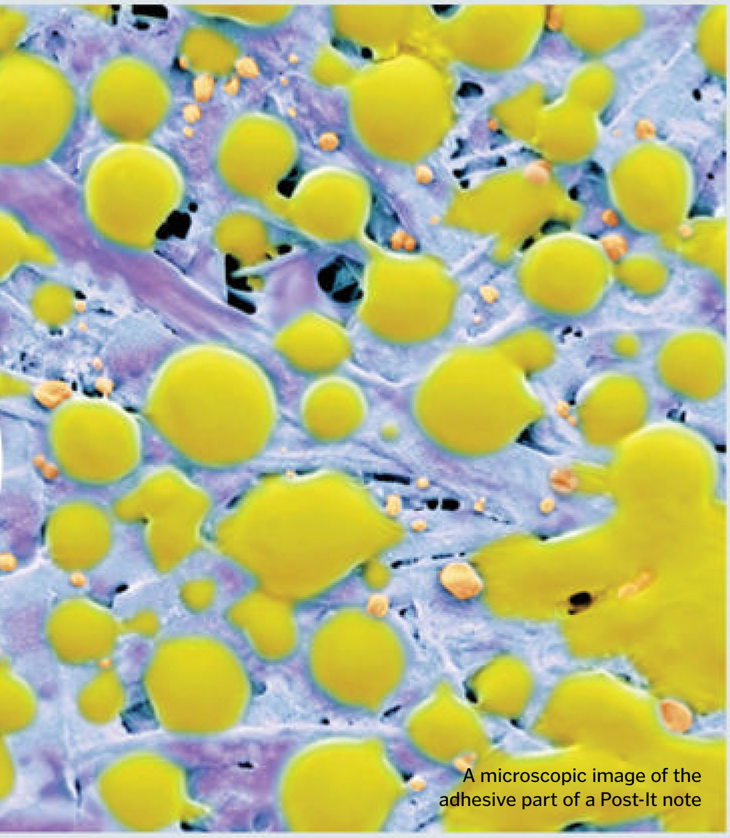
**5. Washing away**
The water runs down the window, taking with it the smaller, more easily removed dirt particles.

**6. Streak free**
As the water has spread into a sheet rather than droplets, it leaves clean, streak-free windows.

# What's in a Post-It note?

## The incredible science behind sticky paper memos

Each Post-It note has a strip of pressure-sensitive adhesive on the back. The adhesive enables notes to stick to a surface, but it does not bond too tightly so notes can be easily removed. The exact composition of Post-It adhesive is a closely guarded secret, but chemists who have studied it believe the glue contains microscopic bubbles. These bubbles rupture under pressure, creating tiny vacuums that act like suction cups to stick the note to a surface. The notes will continue to stick after multiple uses until all the bubbles have been burst so no further vacuums can form.



A microscopic image of the adhesive part of a Post-It note

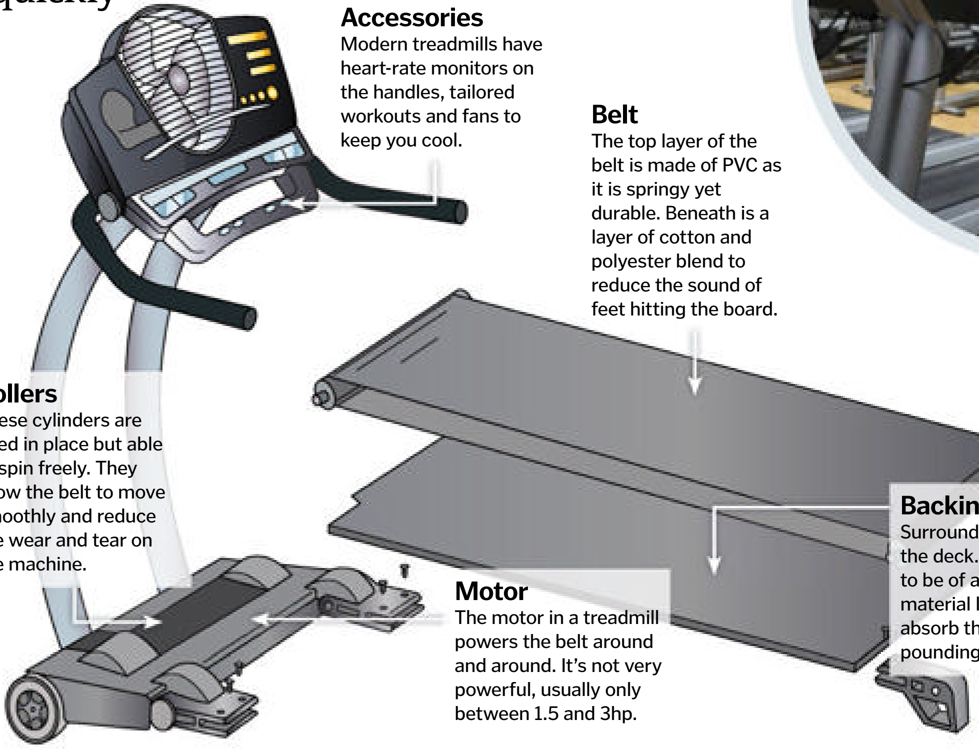
© Science Photo Library; Thinkstock

# How treadmills work

## How to go nowhere very quickly

In just 50 years, treadmills have evolved from a novelty item shown at trade shows to the staple of gyms and fitness rooms worldwide. Originally invented as a medical device for testing the cardiac health of patients, the treadmill was commercialised by William Staub, a Philadelphia-born engineer.

Staub was a fitness fanatic and developed the running machine in the late-1960s as a way of exercising without having to leave the house. Due to its practicality and relatively cheap price point he was selling 2,000 per year by the 1980s and 35,000 per year the following decade. The technology advanced, offering varied workout programmes, heart-rate monitors and emergency stop buttons.



**Accessories**
Modern treadmills have heart-rate monitors on the handles, tailored workouts and fans to keep you cool.

**Belt**
The top layer of the belt is made of PVC as it is springy yet durable. Beneath is a layer of cotton and polyester blend to reduce the sound of feet hitting the board.

**Rollers**
These cylinders are fixed in place but able to spin freely. They allow the belt to move smoothly and reduce the wear and tear on the machine.

**Backing**
Surrounding the belt is the deck. This will need to be of a sturdy material like steel to absorb the repeated pounding of feet.

**Motor**
The motor in a treadmill powers the belt around and around. It's not very powerful, usually only between 1.5 and 3hp.

Angle grinders are versatile tools – here's one serving as a power saw

# Angle grinders explained

## This DIY must-have can take on just about any job

Angle grinders are multi-purpose tools that can do almost everything, from polishing surfaces to shearing through steel. They can either be battery powered or work off the mains and consist of a powerful motor running a spinning disc, which is at a right angle to the handle.

If a wire brush is placed on the spindle, it becomes an excellent tool for removing dried mud or cement from a spade, acting like a high-speed brush.

Alternatively, a sharp-edged blade whirring at high speeds can easily slice through metal or score through tiles and stone. The rapid movement of the blade means the cut will be clean and smooth, rather than jagged and coarse, like a hacksaw cut would be.

They can also be fitted with a grinding wheel that, when run up and down a blade, can sharpen it by shearing off tiny slivers of metal. Angle grinders rotate at around 10,000rpm – ten times the speed of a normal drill motor – and you'll probably find one in nearly every DIY lover's shed.

© Thinkstock

## KEY DATES
MOWING MILESTONES

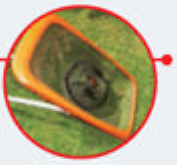
**1827**
Edwin Budding brings out the first lawn mower, aimed at maintaining sports fields and big gardens.

**1859**
A new quieter version of the mower is released, which employs a chain rather than a roller to transfer power.

**1893**
James Sumner patents the first steam-powered lawn mower. Petrol-based mowers quickly follow.

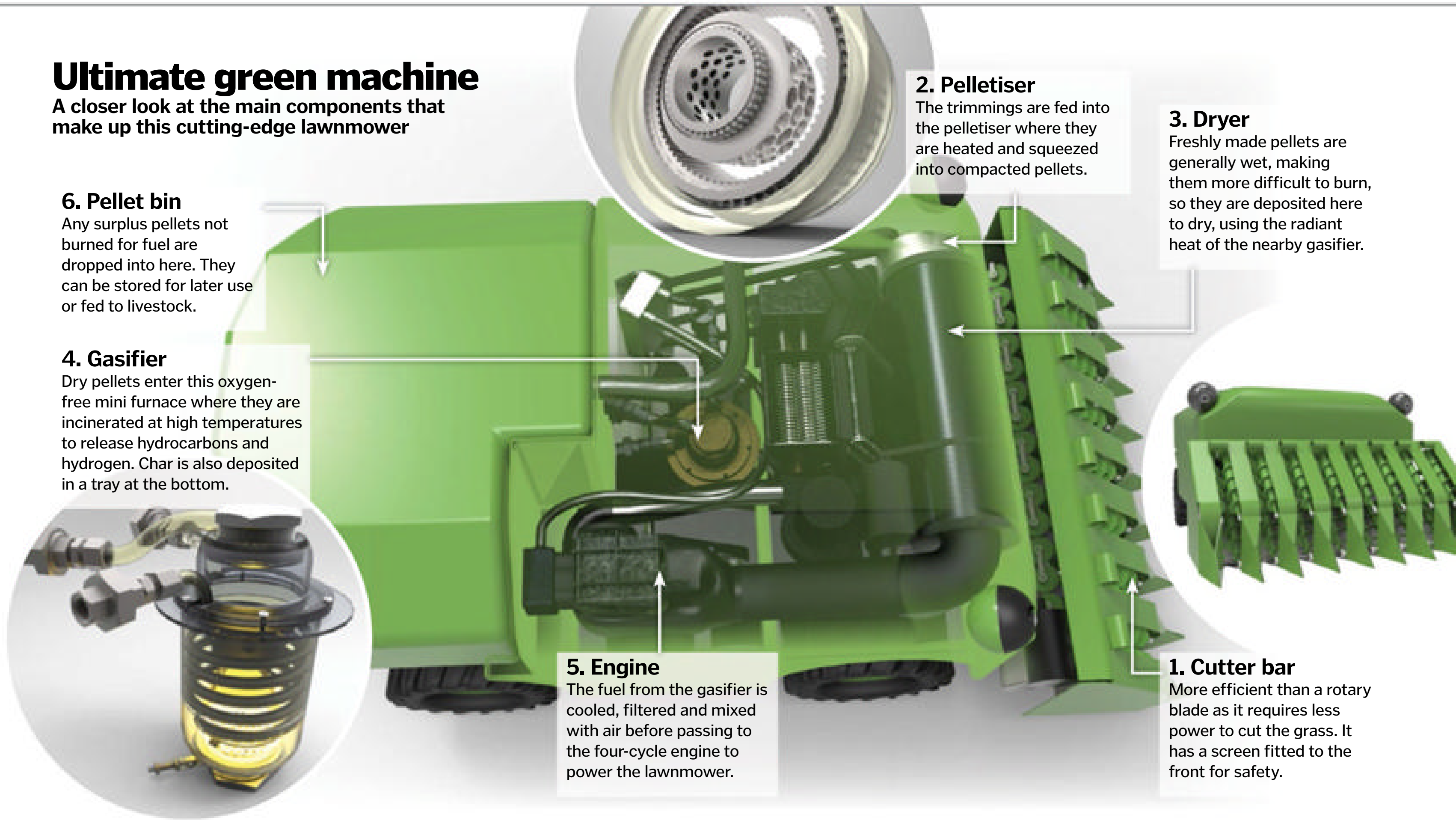
**1922**
The first ever self-propelled ride-on grass-cutting tractor – called the Triplex – goes on sale in the USA.

**1964**
The first Flymo hover mower arrives, using a fan above the blade to generate a cushion of air.



**DID YOU KNOW?** As well as being eco-friendly the EcoMow can navigate itself using GPS technology and on-board sensors

## Ultimate green machine
**A closer look at the main components that make up this cutting-edge lawnmower**



**1. Cutter bar**
More efficient than a rotary blade as it requires less power to cut the grass. It has a screen fitted to the front for safety.

**2. Pelletiser**
The trimmings are fed into the pelletiser where they are heated and squeezed into compacted pellets.

**3. Dryer**
Freshly made pellets are generally wet, making them more difficult to burn, so they are deposited here to dry, using the radiant heat of the nearby gasifier.

**4. Gasifier**
Dry pellets enter this oxygen-free mini furnace where they are incinerated at high temperatures to release hydrocarbons and hydrogen. Char is also deposited in a tray at the bottom.

**5. Engine**
The fuel from the gasifier is cooled, filtered and mixed with air before passing to the four-cycle engine to power the lawnmower.

**6. Pellet bin**
Any surplus pellets not burned for fuel are dropped into here. They can be stored for later use or fed to livestock.

# Inside eco-mowers

Meet the 21st-century lawnmowers which have been designed to run off the very same grass cuttings we normally throw away

Invented in the 1820s, the earliest lawnmowers were surprisingly eco-friendly but fairly hard to operate, typically made out of heavy cast iron and with relatively small blades, although some agricultural varieties were bigger and used farm animals for pulling power.

By the time motorised versions rolled up decades later, this situation had reversed. The machines were easier to use but produced petrol fumes detrimental to the environment. Later electric models didn't generate pollution directly, but still relied on fossil fuels, and also came with the risk of electrocution.

Eco-mowers use 21st-century technology to get the best of both worlds: a mower that cuts the lawn by itself with super-green credentials. A cutter bar has replaced the traditional rotary blade, which consumes far more energy in order to keep it spinning. The grass then enters a pelletiser where the loose trimmings are compressed into pellets using a combination of heat and pressure.

The grass pellets then enter a small chamber to be dried and next comes the most crucial component of the eco-mower: the gasifier. Sealed off to prevent oxygen getting in, it subjects the dried-out pellets of grass to extreme temperatures (up to 1,250 degrees Celsius/2,282 degrees Fahrenheit). In a process known as pyrolysis the biomass releases hydrogen and other hydrocarbons, which, along with air, can then be fed into the engine.

All that's left over from pyrolysis is carbon char, which is by no means waste either, as ongoing research is revealing an ever-wider range of applications for it. This includes compression into charcoal briquettes, water treatment and even improving soil quality on overused agricultural land.

## Waste power
Grass trimmings are not the only waste product generating power around the world today. Used vegetable oil (UVO) from factories and fast-food restaurants can be processed and used as an alternative to diesel in cars and public transport. In Norway, tons of household rubbish are being incinerated to heat water and generate electricity for areas of Oslo. Perhaps most surprising of all, though, are pioneering projects (like one in Ghana) that are converting sewage into reusable products – including fertiliser and biofuel. It also means less sewage is being dumped into the ocean.

© E-Mow/ecomowtech.com

# How do chimneys work?

## Inside the classic household heating system

The fact that hot air is less dense than cold and so rises is vital to the workings of a chimney. In order to vent fumes out of our homes, they rely on a number of scientific principles to work effectively. Thanks to convection currents, pressure differences help fluids – in this case waste gases – move from the fireplace to the roof. This is known as the Venturi effect. Think of the hot fumes as water in a hosepipe. When the tap is turned on, water being forced through the narrow tube increases its speed; the same applies in a chimney.

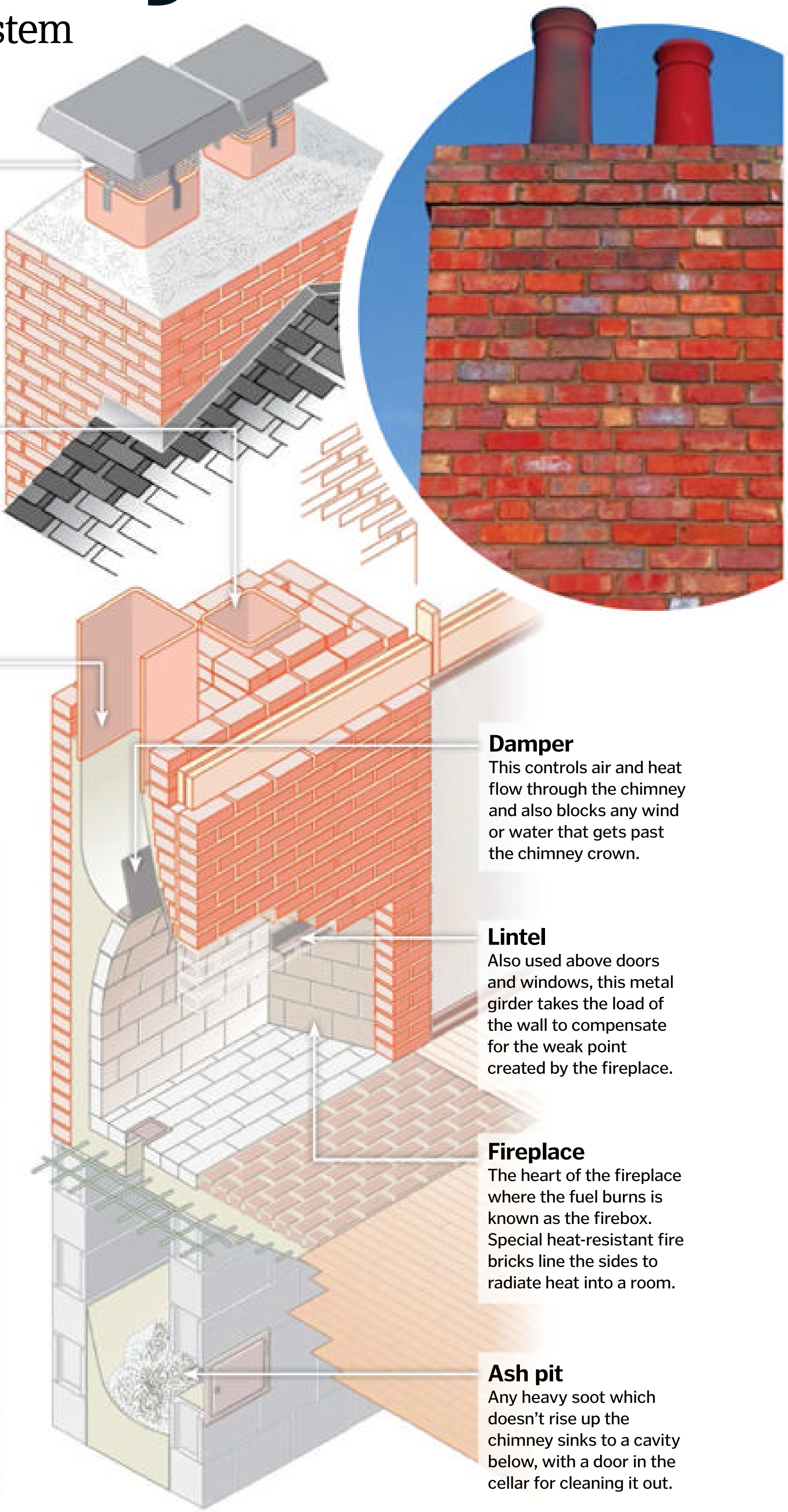
The stack effect also helps speed up the process and works when surrounding cold air is denser than the hot air inside. This ensures that the hotter air always rises. Taller chimneys are more efficient as a higher column of air can build up; around 4.6 metres (15 feet) is considered an ideal height.

On a wider scale than the chimney, every house contains a neutral pressure plane (NPP). Air pressure above this level is higher than outside (positive) and tries to force its way out, while everything below is negative, so air is drawn in. By putting chimneys on the roof we ensure the exit point is as far above the NPP as possible so smoke doesn't sink back into the room, though sometimes high winds counteract this pressure differential.

### Chimneys big and small

Chimneys come in all shapes and sizes. Metal variations are quick to install and have push-fit joining so are more versatile and adaptable than their brick equivalents. Made of stainless steel, they are most suitable for coal and wood fires.

Brick chimneys are the type most commonly seen on Britain's rooftops. They are usually lined with clay, which helps insulate as well as extending its life span. Both of these types contain different flues. Flues help retain heat and expel toxic gases. Masonry versions usually have what is known as 'class one.' This is a basic system that relies on the natural rising of the hot air to work. However, the steel variety uses a 'class two', which is a more complex series of pipes. These can either be metal or a small brick vent.



**On the roof**
Vents raised off the roof emit the smoke away from the building, while chimney caps stop water, birds or other large debris getting in.

**Flue #2**
A second flue deals with fumes from the boiler or another fireplace. Dividing the flues helps to reduce creosote buildup.

**Flue #1**
Smoke and hot air naturally travel upwards from the fireplace. Flue efficiency is increased by the Venturi effect and draught.

**Damper**
This controls air and heat flow through the chimney and also blocks any wind or water that gets past the chimney crown.

**Lintel**
Also used above doors and windows, this metal girder takes the load of the wall to compensate for the weak point created by the fireplace.

**Fireplace**
The heart of the fireplace where the fuel burns is known as the firebox. Special heat-resistant fire bricks line the sides to radiate heat into a room.

**Ash pit**
Any heavy soot which doesn't rise up the chimney sinks to a cavity below, with a door in the cellar for cleaning it out.

**RECORD BREAKERS**
**CHIP CHAMP**

**83HRS**

**FRENCH FRY COOKATHON**
Belgian chef Chris Verschueren cooked and served a staggering 15,000 portions of french fries in just 83 hours, taking only a 100-minute break for a shower during the shift.

**DID YOU KNOW?** *Don't feel guilty about using your fryer; some oven chips actually have more fat than deep-fried chips!*

# Deep fryer technology

Cooking the perfect chips requires oil at scorching temperatures, but how do deep fat fryers get so hot and yet remain safe to use?

Deep fat fryers operate at an average temperature of 185 degrees Celsius (365 degrees Fahrenheit), and have a reputation as dangerous kitchen appliances that start fires, but modern equipment has sophisticated technology to both keep the oil hot and protect the cook from potential risks.

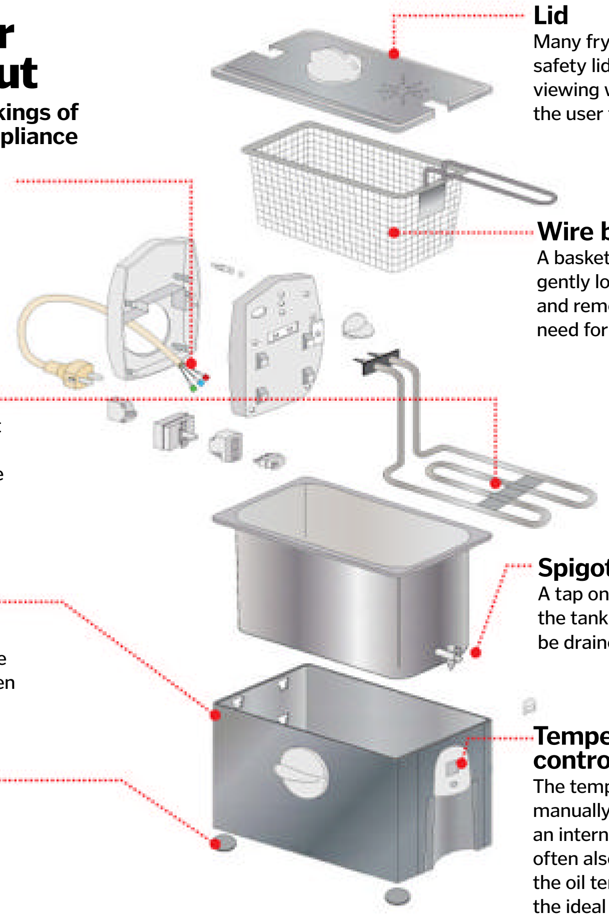
The most important component of the fryer is the mechanism which heats the oil: this can be gas or electric. In an electric fryer a heating element is immersed in the oil, and as an electric current passes through it, resistance generates heat, which is transferred to the oil.

In contrast, gas fryers use gas burners underneath the vat of oil to generate heat. Though these warm up more rapidly, any food particles that sink to the bottom are easily burned, tainting the oil's taste. Gas fryers will often have a 'cool zone' – a dip in the base of the fryer extending below the burners; remaining cooler. Sinking particles drop into this recess.

Many oils will ignite at 260 degrees Celsius (500 degrees Fahrenheit), so modern fryers often incorporate a microchip which shuts off the power should the oil begin to overheat. Many new fryers also have a thermostat that senses and adjusts the temperature, keeping it at optimum heat level.

## Electric fryer inside and out

**A look at the inner workings of this popular cooking appliance**



**Automatic shutdown**
The power will automatically cut out if the oil begins to overheat, preventing it from reaching the temperature at which it might catch fire.

**Heating element**
Electric fryers use an element to heat the oil. The electric current encounters resistance as it moves through the element, generating heat.

**Insulated casing**
The shell of the fryer is often made of plastic, insulating the unit and preventing burns even when the oil is hot.

**Rubber feet**
Sticky rubber feet on the bottom of the fryer prevent it from slipping on or burning the work surface.

**Lid**
Many fryers have a locking safety lid with a clear viewing window to protect the user from spitting oil.

**Wire basket**
A basket allows food to be gently lowered into the oil and removed without the need for utensils.

**Spigot**
A tap on the bottom of the tank allows used oil to be drained easily.

**Temperature control**
The temperature can be manually adjusted, but an internal thermostat is often also used to keep the oil temperature within the ideal range.

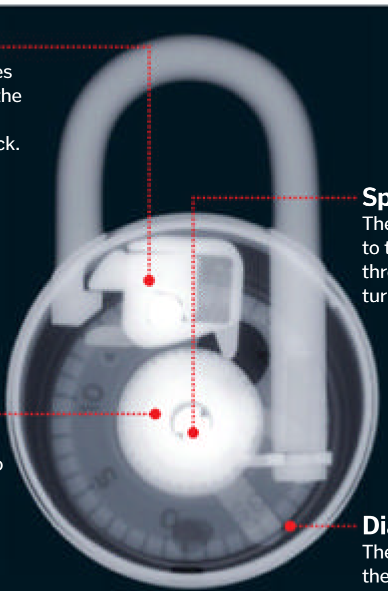
# Combination locks

Discover what is going on at the heart of these traditional security devices…

A combination lock has three notched wheels, which must be lined up to release the latch. The wheels have pins on either side so during rotation one will 'catch' the next.

To open it, the dial is turned clockwise for two rotations – this moves the first wheel, which spins until its pin comes into contact with the second. When the pins collide, the first wheel rotates the second, which picks up the third.

Continuing to turn clockwise to the first number lines the notch on the third wheel up with the latch. The dial is then twisted anti-clockwise, pushing the first and second away from the third wheel's pin. The notch on the second is lined up with the latch and the dial turns clockwise again, moving the first to its position and the lock opens.



**Latch**
When all of the notches in the wheels line up, the latch fits down into them, releasing the lock.

**Spindle**
The spindle is attached to the dial and runs through the wheels and turns the drive cam.

**Wheel pack**
The wheels each have a pin, allowing them to turn as a group.

**Dial**
The external dial moves the drive cam, which in turn spins the wheels.

© Getty; Thinkstock; SPL

# The impact of a nail gun

Meet the nail-slinging power tool putting hammers out of business

Used to drive nails into walls and other surfaces, the nail gun is an automated rival to the manual hammer in many areas of construction and manufacture. Its ability to launch nails at high speed and with relative ease makes the simple hammer seem pretty primitive by comparison.

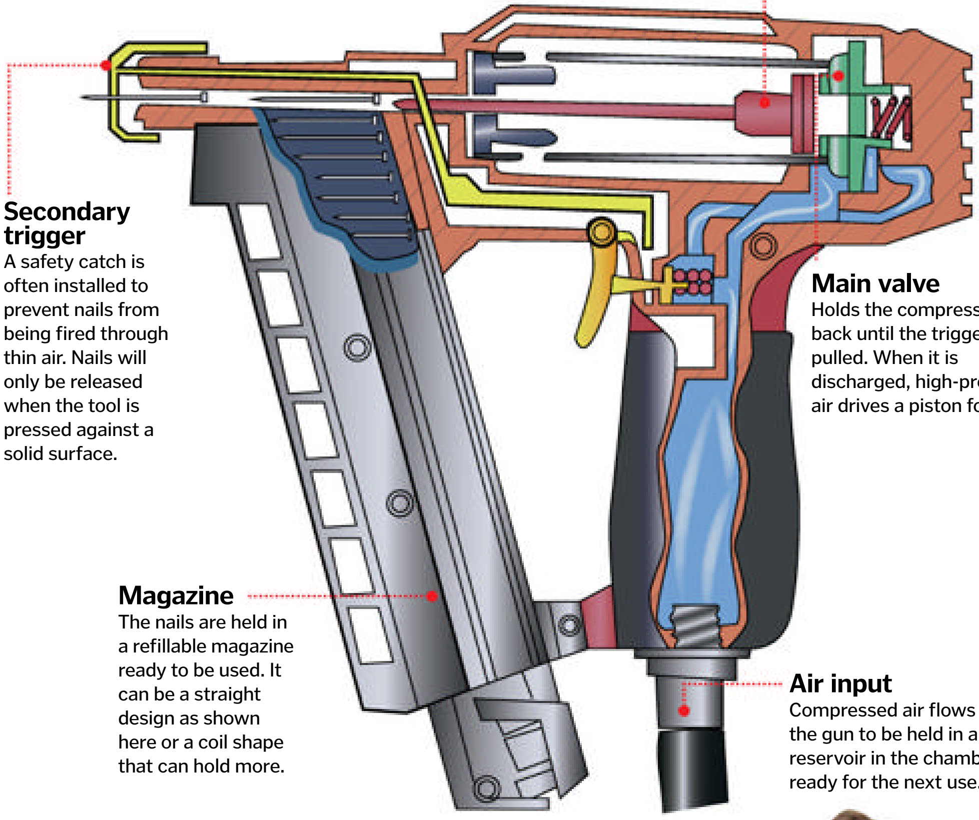
First invented in the 1950s, today there are a range of different nail guns on the market. The most basic is the spring-loaded design. This variation holds one nail at a time and uses a coiled spring to deliver the nail into the desired surface upon the press of the trigger.

Another type is the solenoid – or electromagnetic – nail gun. In this case, the piston is made from a magnetic material, which is either forced out of or drawn into the gun, depending on which way the magnetic current is flowing. Solenoids are more reliable than the spring-loaded design but have a lot less power than pneumatic nail guns (see annotation).

Using compressed air generated from pistons, a pneumatic nail gun can penetrate even the hardest surfaces. Another variation is the combustion nail gun, which ignites flammable gas mixed with air to create a small explosion (like those that power your car engine) forcing the nail out of the chamber. These guns combine power with portability as there is no neeed for an air compressor attachment.

## Inside a pneumatic gun

**Discover the inner workings of an air-powered nail gun**



**Piston**
The piston shoots forward and propels the nails fed from a magazine in front.

**Secondary trigger**
A safety catch is often installed to prevent nails from being fired through thin air. Nails will only be released when the tool is pressed against a solid surface.

**Main valve**
Holds the compressed air back until the trigger is pulled. When it is discharged, high-pressure air drives a piston forward.

**Magazine**
The nails are held in a refillable magazine ready to be used. It can be a straight design as shown here or a coil shape that can hold more.

**Air input**
Compressed air flows into the gun to be held in a reservoir in the chamber ready for the next use.

Nail guns can save a lot of time and energy compared to hammering

## Origins of the nail gun

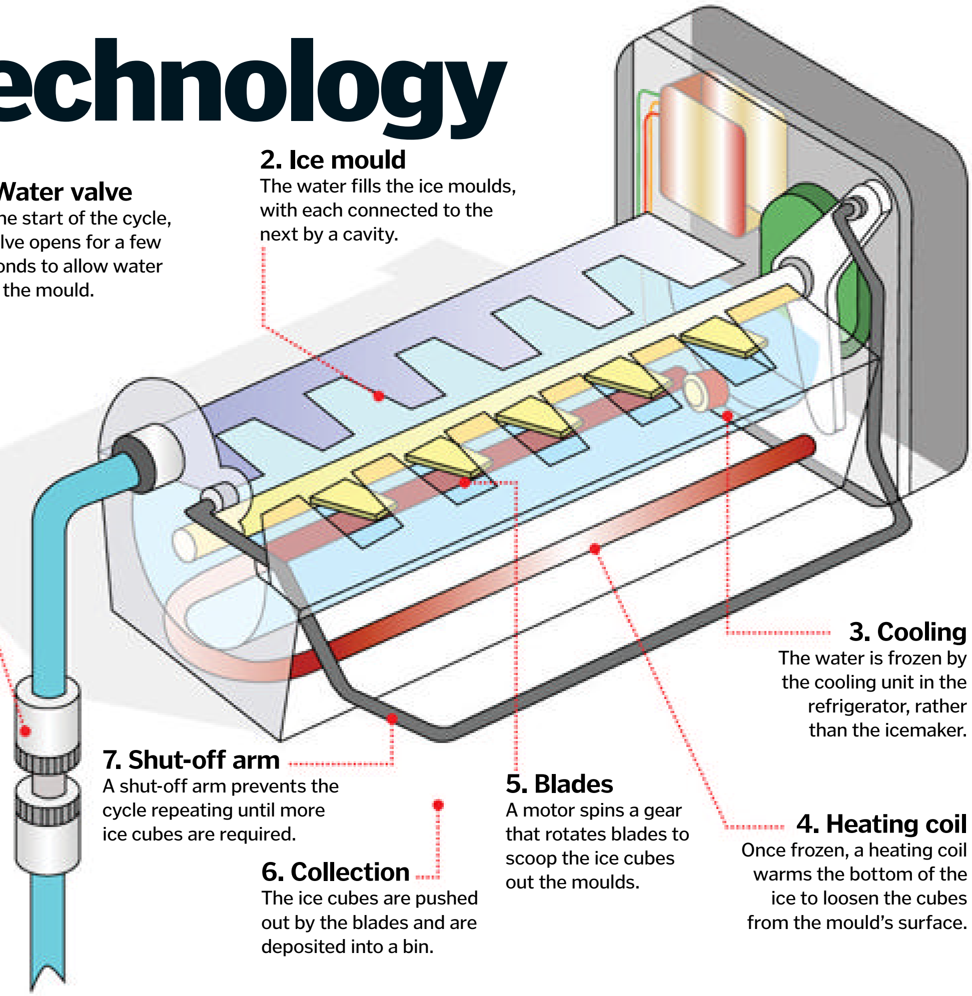
The tool was first invented in the 1950s by three US construction workers – Marvin Hirsch, John Ollig and Reuben Miller – who are thought to have based their idea on the mechanisms of WWII machine guns.

Veterans of the war, they devised the product in a garage and displayed their idea to the Independent Nail Company. Impressed by their invention, the company offered the trio $25,000. They initially declined the offer with a view to starting up their own business, but after running into financial difficulties, the rights were eventually purchased by another firm, Bostitch. Over the following decades, it evolved into the widely used power tool we know today.

# Icemaker technology

## How do these machines produce ice cubes in bulk to keep our drinks cool?

Icemakers are essentially a conveyor belt of ice cubes made for instant use. They come in a variety of shapes and sizes for different purposes, but almost all use the method of freezing water in a mould and then heating it slightly so the ice cubes slide out with ease. Here we look at how a conventional icemaker built into a domestic fridge-freezer works, like the one pictured below.



**1. Water valve**
At the start of the cycle, a valve opens for a few seconds to allow water into the mould.

**2. Ice mould**
The water fills the ice moulds, with each connected to the next by a cavity.

**3. Cooling**
The water is frozen by the cooling unit in the refrigerator, rather than the icemaker.

**4. Heating coil**
Once frozen, a heating coil warms the bottom of the ice to loosen the cubes from the mould's surface.

**5. Blades**
A motor spins a gear that rotates blades to scoop the ice cubes out the moulds.

**6. Collection**
The ice cubes are pushed out by the blades and are deposited into a bin.

**7. Shut-off arm**
A shut-off arm prevents the cycle repeating until more ice cubes are required.

# Solar-powered rubbish bins

## They crush our litter, send an email when they are nearly full and are powered entirely by the Sun – but what tech makes these trash cans so sophisticated?

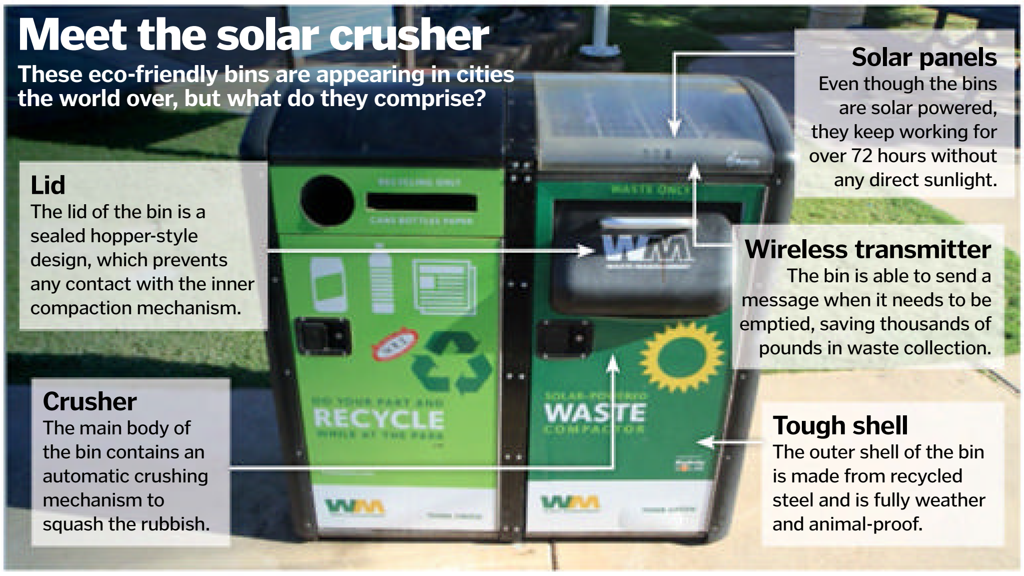
Solar-powered bins contain a sensor to detect when they're full. When litter reaches the sensor, an internal compaction mechanism is activated, crushing the rubbish. The bins can hold up to eight times more refuse: a capacity of 800 litres (180 gallons).

The compaction mechanism runs on a 12-volt battery and does not use hydraulic fluid, so requires very little power. This enables the bins to be used in areas that receive little sunlight; in fact, they can even work in the shade – most need eight hours of sunlight a month for the compactor and internal components.

Many solar-powered bins include a sensor connected to a wireless cellular data transmitter, which sends a signal to local waste disposals when the bin is 85 percent full, making the collection process more efficient.

### Meet the solar crusher

**These eco-friendly bins are appearing in cities the world over, but what do they comprise?**



**Solar panels**
Even though the bins are solar powered, they keep working for over 72 hours without any direct sunlight.

**Lid**
The lid of the bin is a sealed hopper-style design, which prevents any contact with the inner compaction mechanism.

**Wireless transmitter**
The bin is able to send a message when it needs to be emptied, saving thousands of pounds in waste collection.

**Crusher**
The main body of the bin contains an automatic crushing mechanism to squash the rubbish.

**Tough shell**
The outer shell of the bin is made from recycled steel and is fully weather and animal-proof.

© Thinkstock; Alamy

# Homes of the future

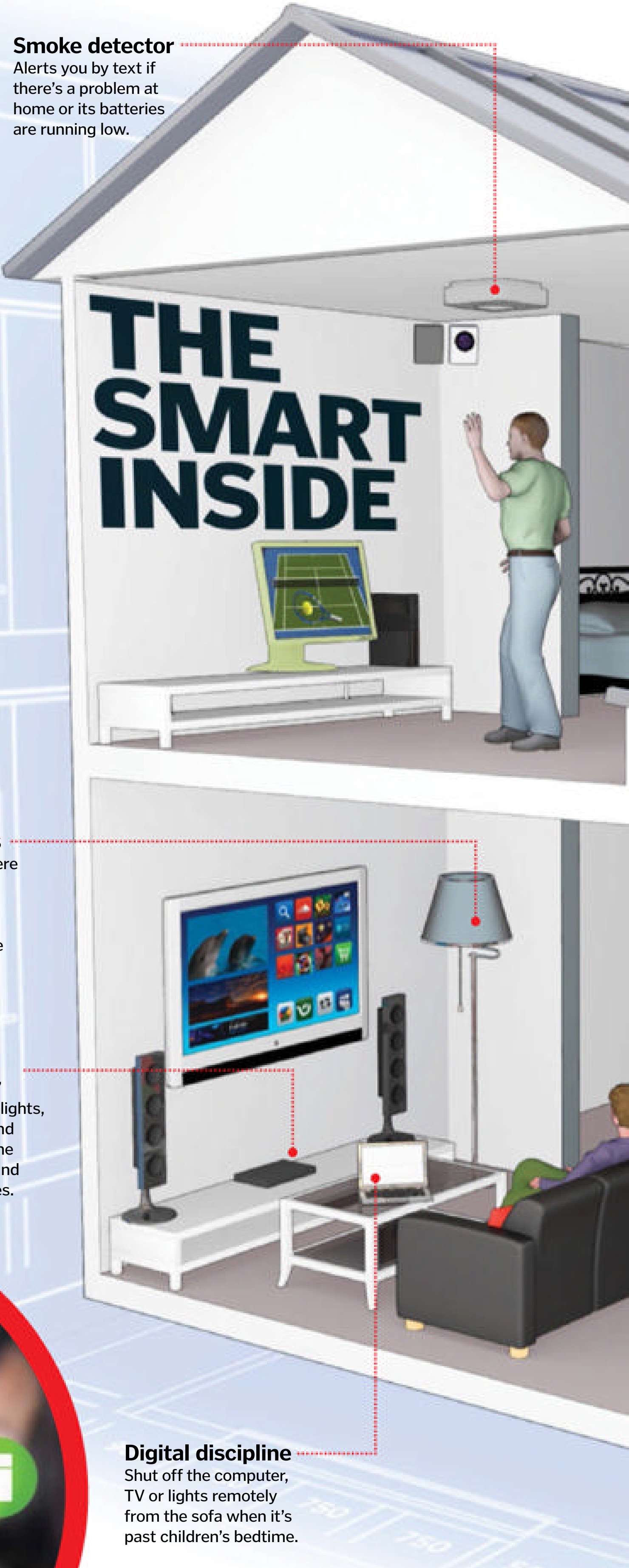
## Now that smartphones are everywhere, get ready for the smart home!

We've all been there. Halfway to the airport and suddenly gripped by the unshakable fear that we've forgotten to switch off the oven or lock the windows. With a smart home, you can put your mind at rest and fix any little oversights, all from your phone as you speed toward your flight.

In a smart home, all the electronic devices are connected to one another in one controllable network, allowing inhabitants to interact with their homes like never before and offering greater comfort, convenience, personalization, energy savings and opportunities for fun!

Want your coffee maker to crank up downstairs as soon as you throw back your sheets? A smart home will let you arrange that. Want to start the bread maker churning and the pool heating as you leave the office? You can do that too. Want your home to learn your habits and help cut your energy consumption, or to notify you if it senses anything untoward like an intruder? No problem at all.

The basis for all these technological advances is the 'Internet of Things' – the exponentially expanding web of devices that are connected to the internet, allowing them to talk to each other and to you, transforming the way we live.



**Smoke detector** Alerts you by text if there's a problem at home or its batteries are running low.

**Smart bulbs** Create atmosphere without leaving your seat, by fine-tuning intensity and hue from your tablet.

**Movie night** Selecting 'movie' setting dims the lights, activates surround sound, fires up the popcorn maker and lowers the shades.

**Digital discipline** Shut off the computer, TV or lights remotely from the sofa when it's past children's bedtime.

smart home
home control

## 5 TOP FACTS SMART HOME STARTER KITS

**Smart socket**

1 For just £40 ($67), the Belkin WeMo switch transforms ordinary electronic devices into smart gadgets you can control and schedule from your phone.

**Leading light**

2 A LIFX LED smart bulb might set you back £80 ($135), but will reward your investment with 27 years of kaleidoscopic colour and smart functionality.

**Thoughtful thermostat**

3 By learning and adapting to your schedule, the Nest Learning Thermostat should pay for its £180 ($300) price tag within a couple of years in most UK households.

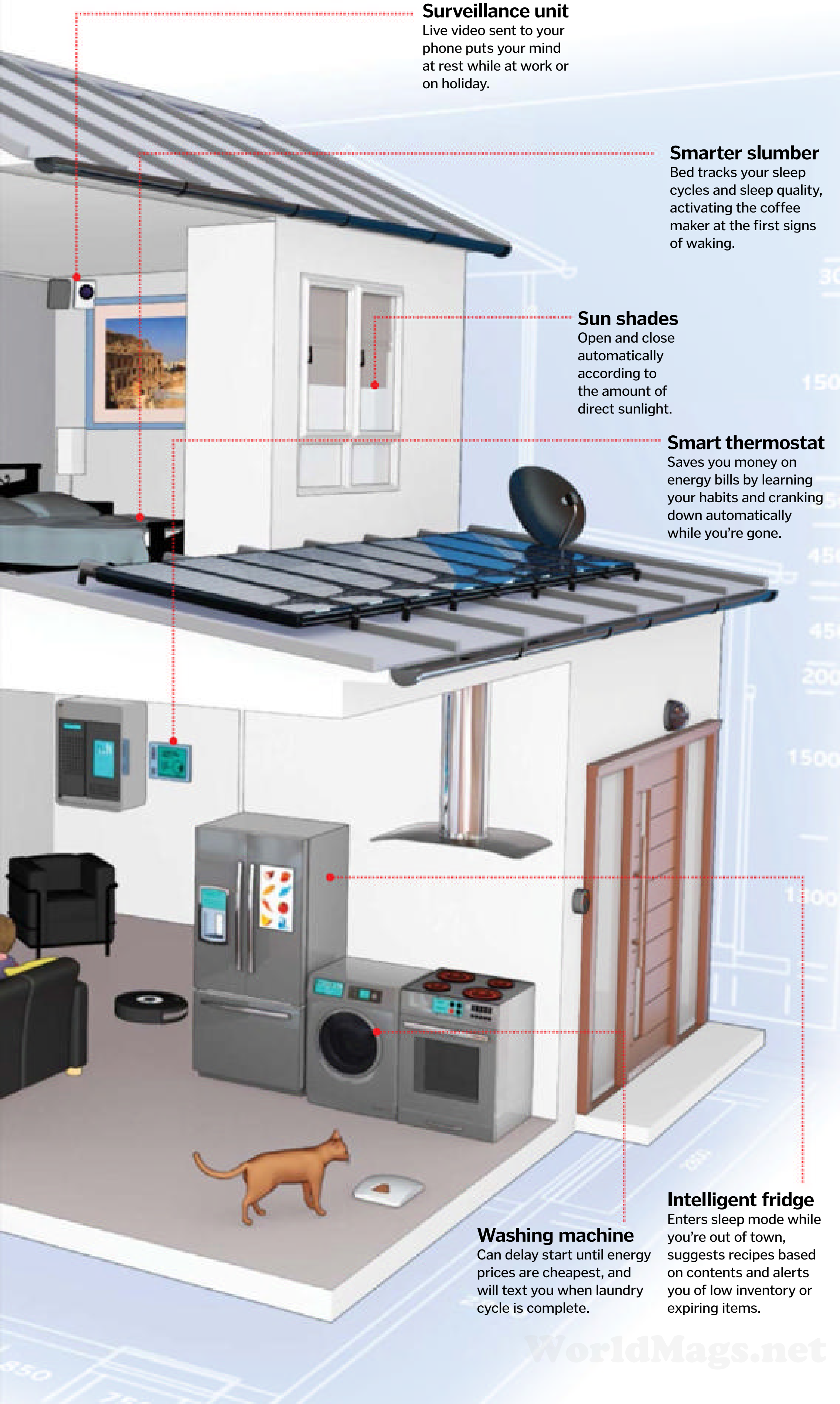
**Smoke signal**

4 Smoke and CO detector Nest Protect will talk to you before howling, so you can deactivate it, discard your burnt toast and save face. Not bad for £90 ($150).

**Security surveillance**

5 The Canary home security system, available soon for about £120 ($200), is a pint-sized surveillance unit that alerts your phone if it detects unusual activity while you're out.

**DID YOU KNOW?** The USA's smartest home is owned by SmartThings CEO Alex Hawkinson and includes over 150 connected devices



**Surveillance unit**
Live video sent to your phone puts your mind at rest while at work or on holiday.

**Smarter slumber**
Bed tracks your sleep cycles and sleep quality, activating the coffee maker at the first signs of waking.

**Sun shades**
Open and close automatically according to the amount of direct sunlight.

**Smart thermostat**
Saves you money on energy bills by learning your habits and cranking down automatically while you're gone.

**Washing machine**
Can delay start until energy prices are cheapest, and will text you when laundry cycle is complete.

**Intelligent fridge**
Enters sleep mode while you're out of town, suggests recipes based on contents and alerts you of low inventory or expiring items.

## Talking to your tech

### Tracking the growth of the Internet of Things

**20%** NUMBER OF USA ADULT INTERNET USERS WHO ALREADY OWN A DEVICE THAT CONNECTS THE PHYSICAL ENVIRONMENT TO THE INTERNET [FORRESTER]. THIS WILL RISE TO 50% BY 2020 [PARK ASSOCIATES]

NUMBER OF FULL HOME AUTOMATION SYSTEMS INSTALLED IN THE USA IN 2012 [ABI RESEARCH] **1.5 million**

**224 million** NUMBER OF HOMES WORLDWIDE (1 IN EVERY 8.5 HOMES) THAT WILL HAVE SOME SORT OF SMART HOME TECHNOLOGY INSTALLED BY 2019 [STRATEGY ANALYTICS]

**10%** NUMBER OF US HOMEOWNERS AGED 25-34 WHO OWN AT LEAST ONE SMART ENERGY DEVICE [PARK ASSOCIATES]

**1 in 9 (11%)** NUMBER OF UK HOUSEHOLDS THAT WILL BE USING AT LEAST ONE SMART DEVICE BY THE END OF 2014. THIS NUMBER WILL JUMP TO OVER 1 IN 4 (27%) JUST FIVE YEARS FROM NOW [STRATEGY ANALYTICS]

**$7.8 billion** (£4.6 BILLION) PREDICTED SIZE OF THE DIY SMART HOME MARKET BY 2019, UP FROM $1.3 BILLION (£770,000) TODAY [NEXTMARKET INSIGHTS]

**150** NUMBER OF INTERCONNECTED DEVICES IN USA'S 'SMARTEST' HOME [HUFFPO VIDEO INTERVIEW WITH OWNER]

**20%** AMOUNT AN AVERAGE USER COULD SAVE ON THEIR ENERGY BILL BY INSTALLING A NEST LEARNING THERMOSTAT [NEST]

THE NUMBER OF US HOMES WITH PROGRAMMABLE THERMOSTATS JUMPED BY THIS MUCH BETWEEN 2012 AND 2013 [CONSUMER ELECTRONICS ASSOCIATION] **7%**

**£234** OR $393, AVERAGE TECHNOLOGY SPEND OF UK SMART-HOME OWNERS, LESS THAN HALF THAT OF THEIR US EQUIVALENTS (£517 / $868) [STRATEGY ANALYTICS]

# Homes of the future

Automated home electronics have been on the scene for decades, but only recently have they been able to begin talking to one another and functioning in concert. That's largely thanks to the advent of efficient low-cost wireless protocols – think Wi-Fi, Bluetooth, mobile phone networks – in the early-2000s, which use radio waves to transmit messages wirelessly.

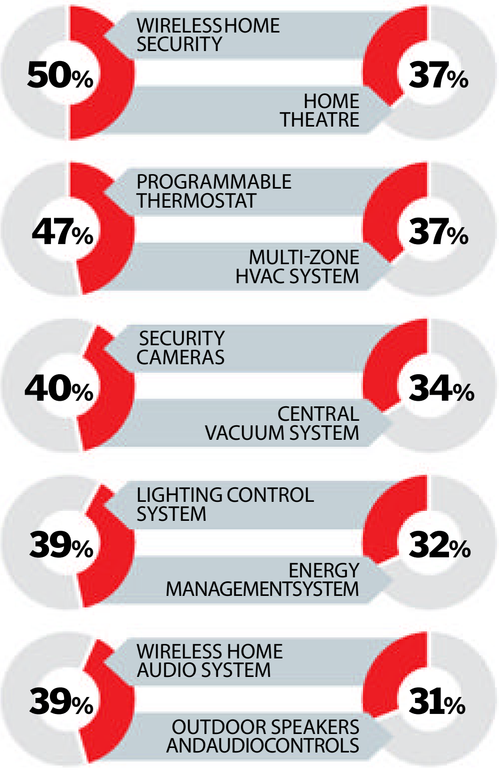
ZigBee and Z-Wave are similar protocols that can be thought of as low-power, short-range versions of Wi-Fi. They are ideal for use inside the smart home because they're optimised for transmitting small amounts of data – like messages to and from smart devices – through walls and furniture, over the range needed for a typical household.

Smart devices are connected via these wireless networks to a central hub where they can be controlled with a tablet or smartphone. They can also be programmed to carry out any action based on the logic command 'If This Then That', or IFTTT (rhymes with lift). IFTTT lets you dictate what action a device should take for a given stimulus.

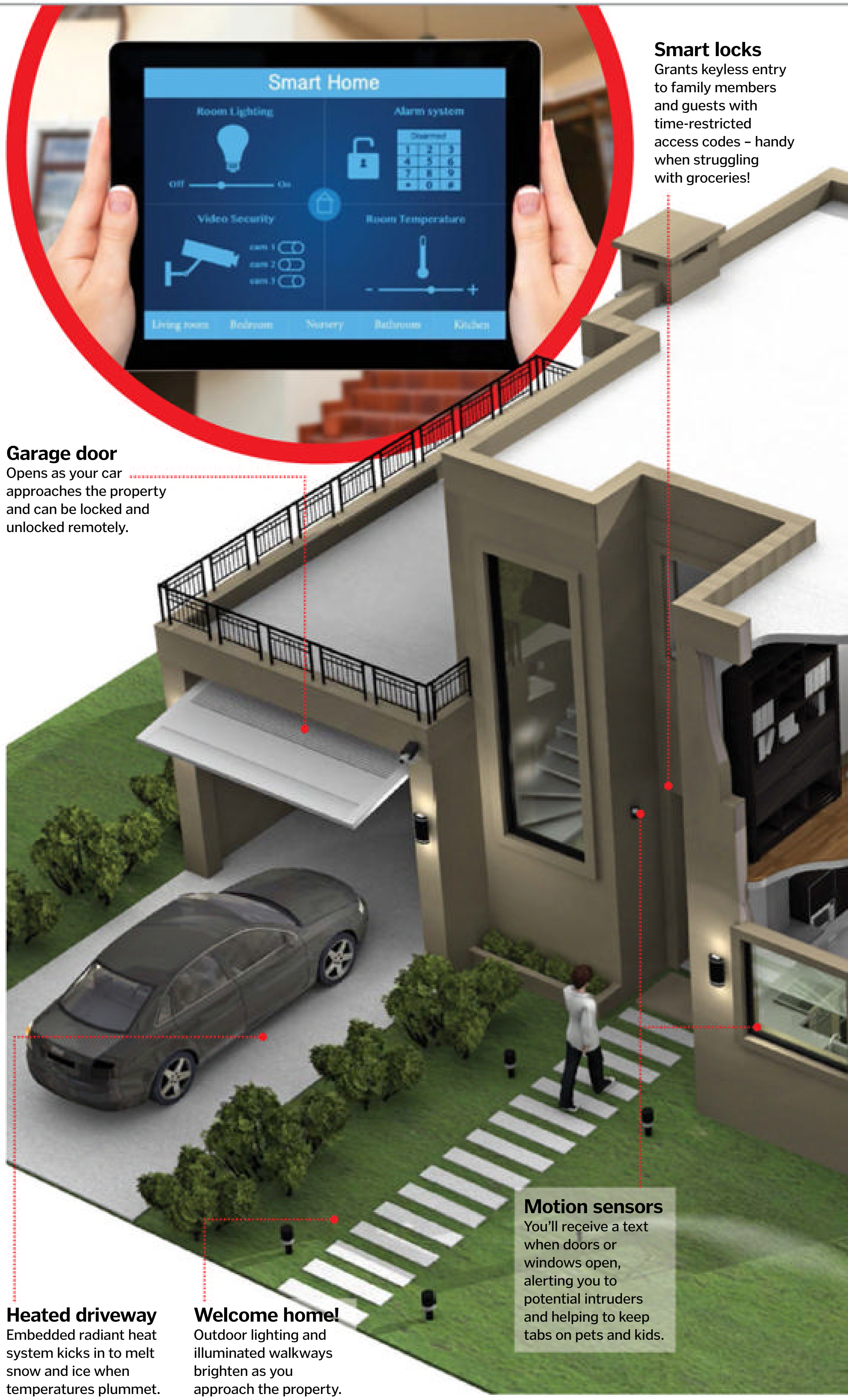
For example, announcing to your TV, "It's movie time", might lower the shades, dim the lights, activate your surround sound system and fire up the popcorn maker. Now that's smart.

## Homeowner wish list

**Top ten most coveted smart technologies***



*data from National Association of Home Builders



**Smart locks**
Grants keyless entry to family members and guests with time-restricted access codes – handy when struggling with groceries!

**Garage door**
Opens as your car approaches the property and can be locked and unlocked remotely.

**Motion sensors**
You'll receive a text when doors or windows open, alerting you to potential intruders and helping to keep tabs on pets and kids.

**Heated driveway**
Embedded radiant heat system kicks in to melt snow and ice when temperatures plummet.

**Welcome home!**
Outdoor lighting and illuminated walkways brighten as you approach the property.

**RECORD BREAKERS**
**SMART MANSION**

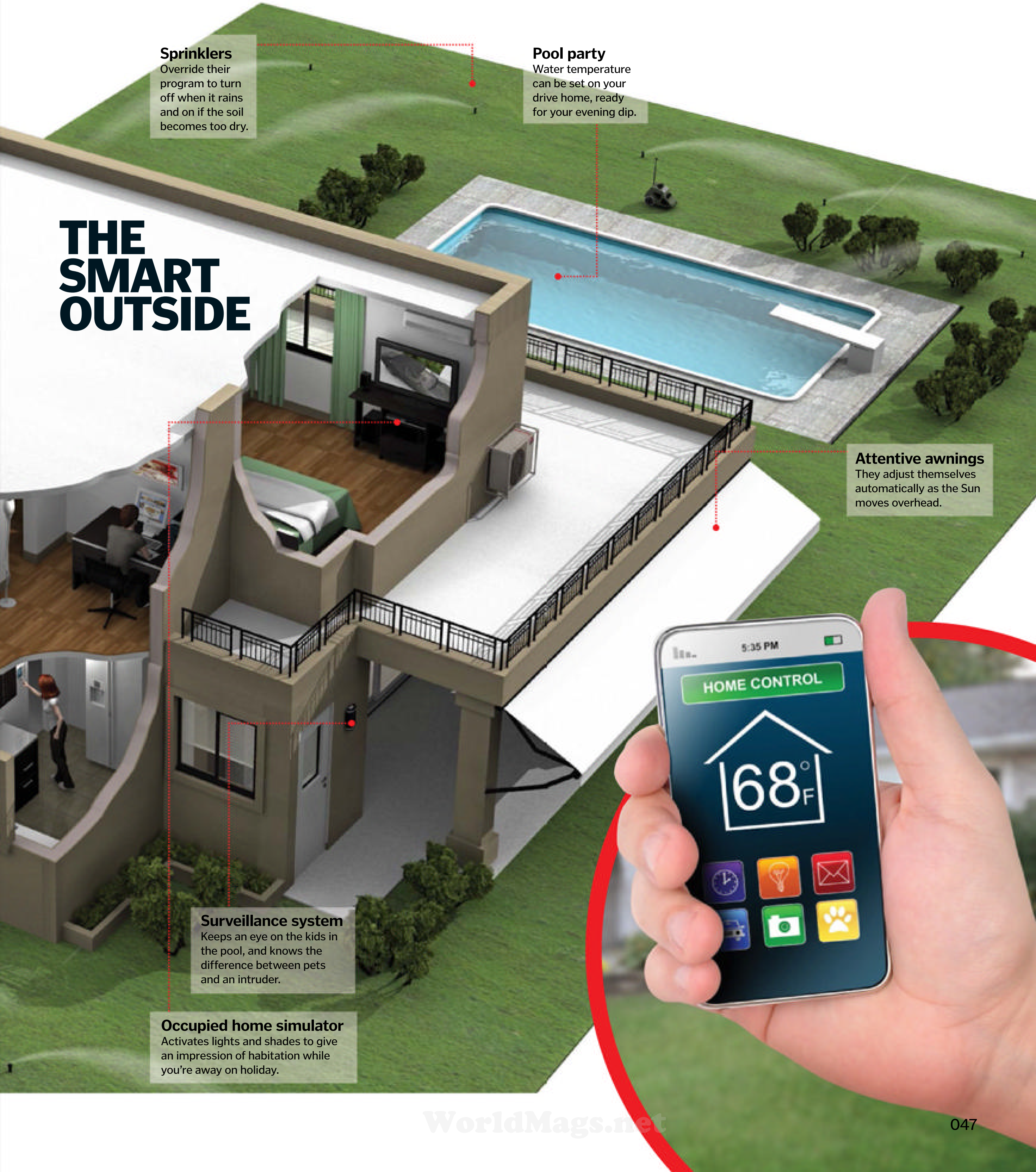
**$120 MILLION**

**MOST VALUABLE SMART HOME**

Bill and Melinda Gates's Pacific lodge-style smart mansion in Medina, USA, is nicknamed Xanadu 2.0 after the title character's estate in *Citizen Kane*.

**DID YOU KNOW?** *X10, a wired connection system made in 1975, was one of the earliest smart-home systems and is still in use today*

# THE SMART OUTSIDE



**Sprinklers**
Override their program to turn off when it rains and on if the soil becomes too dry.

**Pool party**
Water temperature can be set on your drive home, ready for your evening dip.

**Attentive awnings**
They adjust themselves automatically as the Sun moves overhead.

**Surveillance system**
Keeps an eye on the kids in the pool, and knows the difference between pets and an intruder.

**Occupied home simulator**
Activates lights and shades to give an impression of habitation while you're away on holiday.

Until recently, smart homes have mostly been viewed as quirky playgrounds reserved for the super-rich and diehard *Jetsons* fanatics. In the US today, less than one per cent of homes have a full automation system installed, but the picture is changing rapidly. Why?

"What's happening is there's a shift from that past market – which required a professional installer, and more recently a service-provider subscription – to what we're starting to see now: the roll-out of what we call DIY smart homes", explains chief analyst and smart-home expert Michael Wolf of NextMarket Insights in Seattle.

The majority of new smart objects are designed to plug-and-go. New smart-home residents can shop around for devices that best meet their needs, download the apps that make them run, stitch them all together through their humble smartphone, and save themselves a fortune in the process. "That's where we see the potential for much greater adoption, because the barriers in terms of cost and heaviness of the install start to go down", says Wolf.

In 2014, tech giants have rushed to make their first forays into the smart-home market, steering it firmly toward the mainstream. In January 2014, Google acquired Nest Labs – founded by iPod designer Tony Fadell – for £1.9 billion ($3.2 billion). Nest's most popular product, the Learning Thermostat, responds to your routines and preferences, turns itself down when it notices you're away, helping you save energy.

Elsewhere, Microsoft formed a partnership with smart hub and device company Insteon in May, and in June Apple announced that its own Siri-integrated smart-home platform HomeKit would debut as part of the upcoming iOS 8 release this autumn.

So if smart homes offer improved comfort, convenience, security and environmental credentials, for an affordable price, what's the catch? For one thing, the explosion of new products, all running on different protocols, can be hard to integrate; less tech-savvy consumers might want to hold off a year or so while the industry reaches a better consensus.

More troubling is that smart homes, like any internet-connected device, are potentially hackable. What if a burglar finds a way to open your smart lock and disable your intelligent security systems? Others worry that products like Nest give Google even deeper reach into our personal data.

One thing is for certain: whether you're set to be an early adopter or you're still on the fence, this is only the beginning for smart homes.

## Next big things

Welcome home! Check out some of the features of your oh-so-smart future abode...

### Witt induction hobs

www.witt-ltd.com

Induction multizones sunk into the work surface automatically detect where a pan is placed; shut off when a pan is removed, overflows, or boils dry; and offer a pause function if you need to walk away suddenly.

### Feed & Go Online Automatic pet feeder

www.feedandgo.com

All the scheduling and dispensing features of a traditional automatic feeder, plus a camera so you can share every gory detail of your pet gobbling up its dinner, and a voice recorder so you can leave it a secret mealtime message.

### Lifx LED Bulb

lifx.co

Lets you set endless moods, selecting from over 16 million possible hues in a colour wheel on your smartphone. Can be programmed to brighten and dim slowly at opposite ends of the day, easing you out of and into sleep; to flash when you receive a text or email; and to come on automatically as soon as it detects your smartphone approaching your property. Highly energy efficient, it lasts 27 years.

**DID YOU KNOW?** *A planned miniature smart home for dogs, T-Pai is shaped like a double-decker bus and includes video-call facilities*

## Nest Protect

**nest.com**

Combined smoke/carbon monoxide detector gives you a heads up before sounding the full alarm, texts you when its batteries are low, alerts you of hazards detected while you're out and will shut down your Nest Thermostat if it sniffs something untoward.

## Belkin WeMo Switch

**www.belkin.com**

Lets you control any electric appliance remotely from your smartphone. Options to monitor how much energy your devices are consuming, or pair with a motion sensor so that, for example, walking through the front door turns on an appliance in another room.

## Sleep Number Sleep IQ

**www.sleepnumber.com**

Sleep IQ monitors you as you sleep, tracking your heart rate, breathing rate, movements and sleep cycles to calculate the quality of your sleep and help you fine tune details like your bed time, mattress texture and daily habits to attain optimal sleep each and every night. Especially useful if your bedfellow is prone to snoring – Sleep IQ responds to the voice command "Stop snoring!" by gently raising your partner's head while they continue to slumber.

## HomeChat by LG

**lgusblog.com**

With HomeChat you can converse naturally with your appliances to find out what they're up to and make requests. Your fridge might text you to remind you you're running low on milk; you can ask the washing machine, "where are you up to and when will you be done?" You can also set the robot vacuum to work an hour before you return home. They probably won't have any useful relationship advice for you, though.

## PointGrab's PointSwitch

**www.pointgrab.com**

This nifty gadget allows you to control multiple appliances – lights, entertainment systems, air-con and more – from across the room simply by pointing and gesturing, so you won't even need to pick up your smartphone. PointSwitch uses motion-detection algorithms with a standard two-dimensional infrared camera to accurately identify your gesture and its direction. Just remember to turn it off before you start dancing on your own in the lounge…

## Elertus Smart Sensor

**www.elertus.com**

Originally designed to monitor the temperature and humidity of cellars housing prize wines, the Elertus has ballooned into an all-encompassing watchdog that keeps tabs on anything precious to you. As well as clocking temperature and humidity, it will alert you if it detects movement, water, changes in light levels or doors opening and closing.

## LED light transmissive carpet

**www.philips.com**

Carpet transmits light from programmable LED arrays laid underneath it. Use it to highlight the route to the bathroom in the night; guide inhabitants to safety during a fire; deliver instructions, directions or greetings to house guests; or – best of all – recreate the music video for *Billie Jean* right there in your living room. Maybe. No, definitely.

© Sleepnumber; PointGrab; Elertus; LGHomeChat; Philips/Desso; Witt UK & Ireland; Nest; Feedandgo; Belkin; Sol 90

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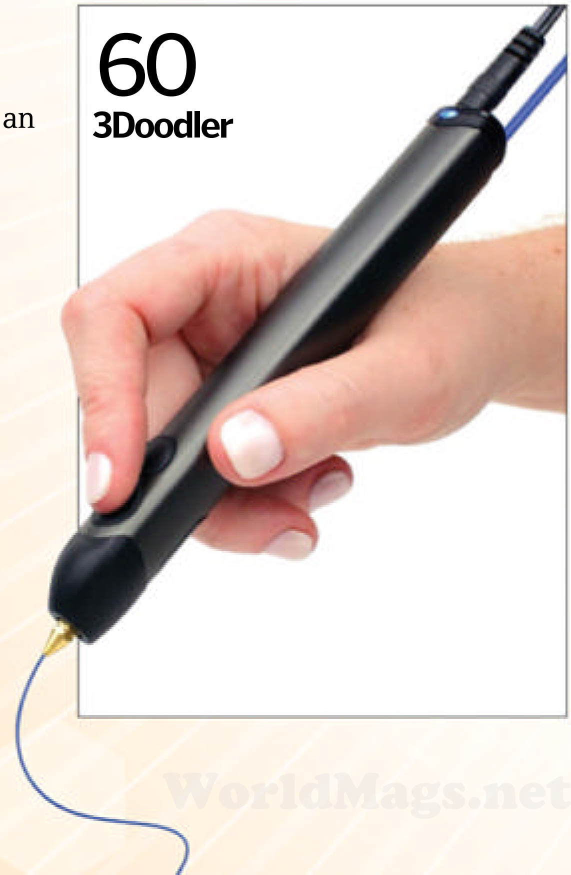
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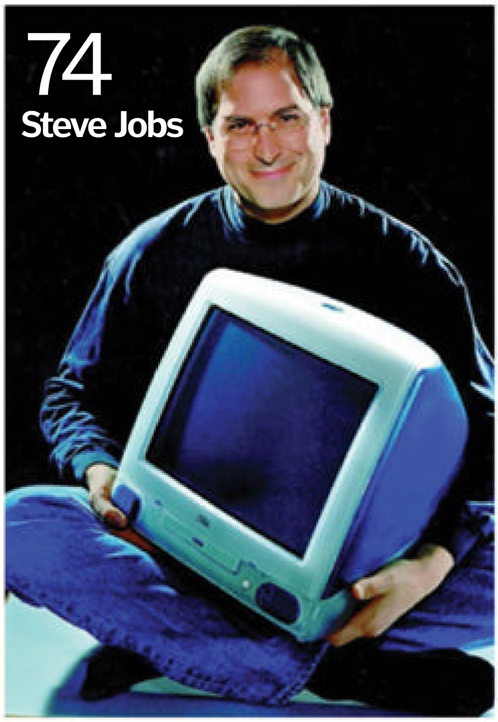
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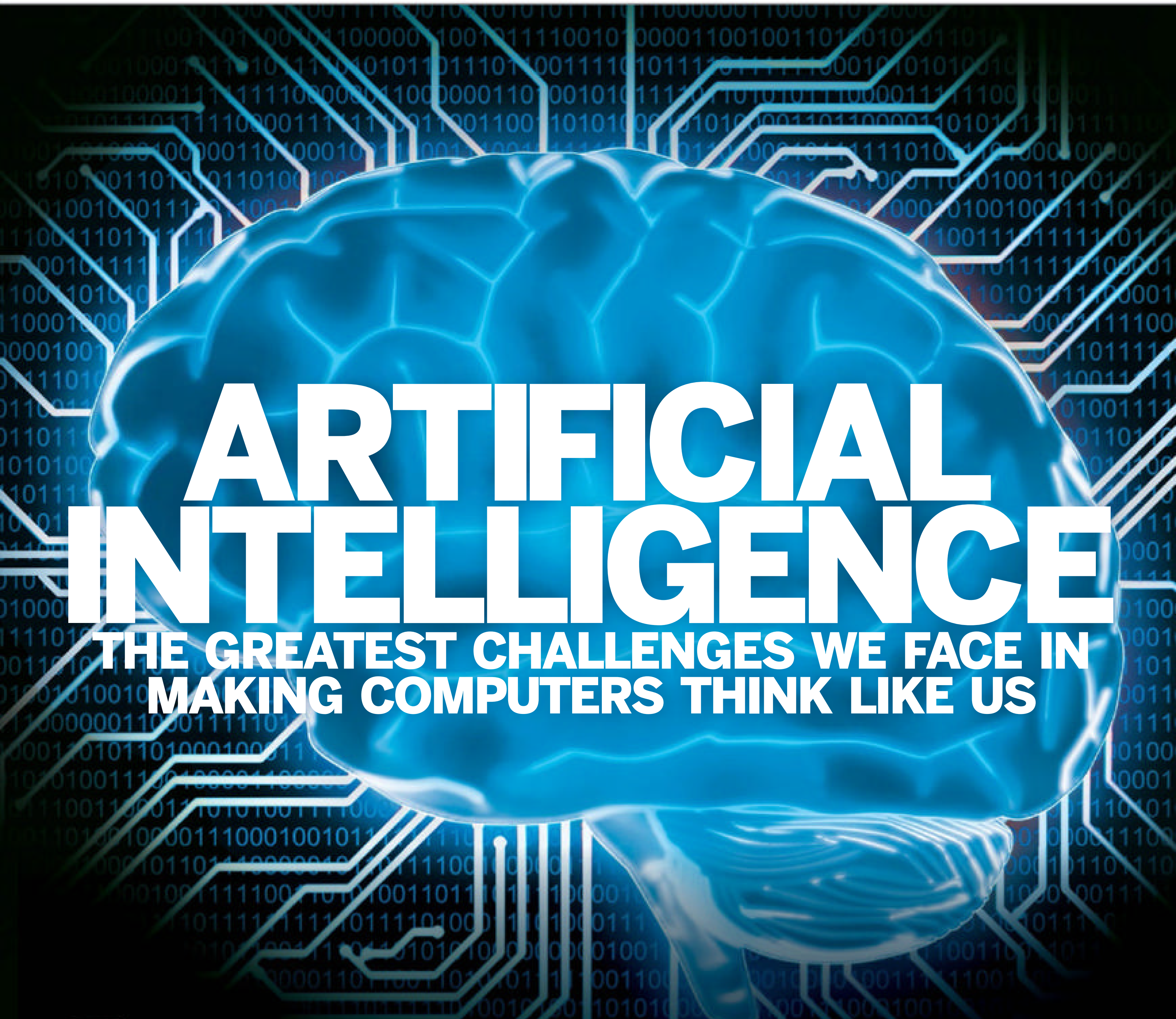


# ARTIFICIAL INTELLIGENCE

## THE GREATEST CHALLENGES WE FACE IN MAKING COMPUTERS THINK LIKE US

Intelligence is a tough concept to pin down. Is someone, or something, intelligent because they can multiply 29 x 18 in their head? What about emotional intelligence – working out if someone is sad, angry or faking an emotion? There's a fair few people who could solve the above sum (it's 522, if you were wondering) but wouldn't have a clue what to do when someone starts bawling their eyes out in front of them. All this makes the field of artificial intelligence a thorny path to tread.

British mathematician Alan Turing, most famous for his codebreaking work at Bletchley Park during World War II, got people thinking about computers as a tool for thought, rather than mere calculations. But where are we now in terms of creating computers and robots that can think, talk and perform tasks like humans? After recent advances in drone and interactive robot technology we are close to a breakthrough in AI, but have a little way to go yet before engineering a Samantha from *Her* or Skynet in *Terminator*.

Oxford University's professor of Computer Science, Nando de Freitas, has spent a lot of time studying the brain, trying to work out what goes on without us knowing it: "There's an area in the brain called the hippocampus, which is fascinating. In a rat, particular neurons will fire when it is travelling in a certain direction, but only for that direction. However, if it is in a different part of the room, a different neuron fires. That is how the rat knows where it is in the room. Each neuron is connected to the visual cortex,

## 5 TOP FACTS
AI LABS

**CSAIL**
1 The Computer Science and Artificial Intelligence Lab at MIT in Boston is one of the world's leading AI hubs, with 28 labs dedicated to artificial intelligence research alone.

**Aldebaran**
2 Commercial robot technology company Aldebaran is responsible for the creation of NAO, an advanced humanoid robot that can play games and interact with people.

**Stanford AI Lab**
3 Founded by AI pioneer John McCarthy in 1962, this lab at Stanford is dedicated to pushing technologies that will benefit humanity in its future progress.

**Quantum AI Lab**
4 A collaboration between Google and NASA, QuAIL focuses its research on developing a completely new kind of intelligence using quantum computers.

**Facebook's AI Lab**
5 NYU professor Yann LeCun is the director of Facebook's AI Lab, aimed at building on Deep Learning research to enhance understanding of its massive global user base.

**DID YOU KNOW?** Despite of what Hollywood says, a robot revolution is unlikely as robots have no survival instinct of their own

where we store images, and the auditory cortex, where we store sequences. Each neuron represents a location in the world and fires when you are there. Every time you excite a neuron in the hippocampus, it fires a certain set of neurons representing an image in the world, meaning, for example, you can now imagine your way home. Right now, we are trying to work out how to do that. We take intelligence for granted. You aren't aware of a lot of what's going on in your brain, which is why it's so hard to reverse engineer it."

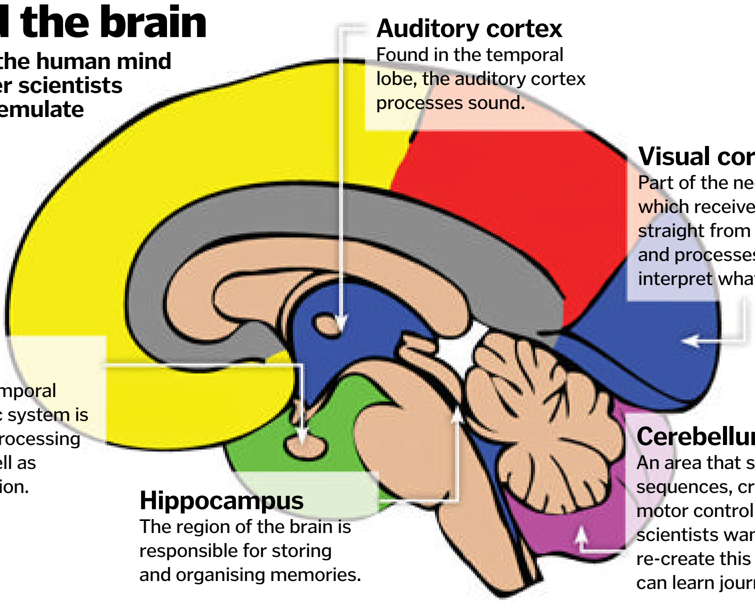
The argument that a robot is unable to be truly intelligent until it can feel emotions like a human is easy to refute. "Emotions are one of the easiest things to reproduce," argues De Freitas. "You don't need to build something as intelligent as a human to get an emotional response. If you were to poke the amygdala with a needle, you'll get an emotional response. That's because the amygdala is part of the old brain, which we share with rats, mice, cows, pigs and lots of other animals. The new brain – areas like the neocortex – is where we do our higher level of thinking."

So if scientists aren't looking at developing robots that get sniffly at *The Notebook*, how are they attempting to create the next generation of thinking robots? After all, we have had Deep Blue, the computer that defeated chess world champion Garry Kasparov in a duel, and Watson, the supercomputer that thrashed two champions in *Jeopardy!* What hurdles are they yet to overcome?

"I see intelligence as being able to interact with an environment and do the right thing," continues De Freitas. "Humans are able to plan their actions and engage in counterfactual reasoning, which is a fancy way of saying 'what if' reasoning. That is being able to perform an action and ask yourself: 'What would happen if I did

## Around the brain

**Key areas of the human mind that computer scientists are trying to emulate**



**Auditory cortex**
Found in the temporal lobe, the auditory cortex processes sound.

**Visual cortex**
Part of the neocortex, which receives images straight from the retina and processes them to interpret what we see.

**Amygdala**
Found in the temporal lobe, this limbic system is involved with processing emotions as well as memory retention.

**Hippocampus**
The region of the brain is responsible for storing and organising memories.

**Cerebellum**
An area that stores sequences, crucial for motor control. AI scientists want to re-create this so robots can learn journeys.

00
$77,147
WATSON

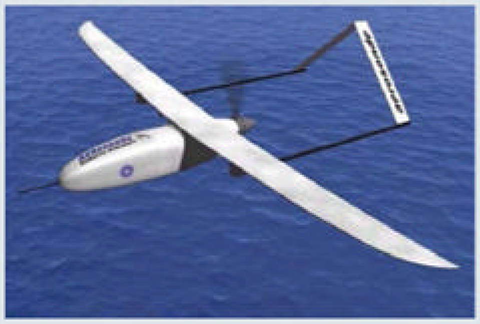
Despite struggling with some shorter clues, Watson easily beat its human rivals

## Brain games

Deep Blue and Watson are amazing examples of supercomputers that were able to defeat the best human practitioners in chess and quiz show *Jeopardy!*, respectively. But what tech went into the duo? Deep Blue beat world chess champion Garry Kasparov in 1997, using its ability to assign values to the various pieces on the board and analyse 200 million moves per second using its AIX operating system and IBM SP Parallel System.

Watson came 14 years later and stunned the world by not only being able to understand the complex questions posed, but formulate a logical response from its stored database in seconds. In order for this incredibly powerful machine to work, Watson used 90 IBM Power 750 computers, which were the same as 2,800 high-speed computers, housing 15 trillion bytes of memory. Interestingly, IBM has recently announced a competition to push developers into incorporating Watson's intelligence into mobile apps.

## AI tech today



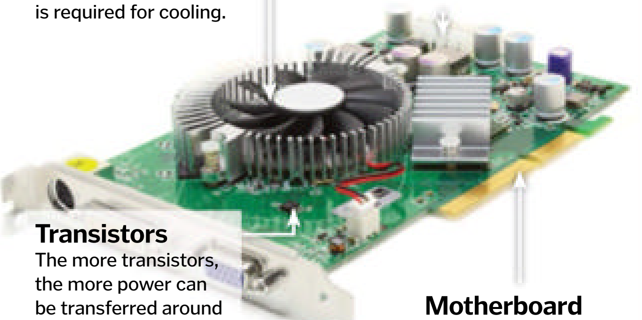
**Drone aircraft**
Unmanned aerial vehicles (UAVs) first emerged in the early-Fifties and can be used in warfare, reconnaissance, aerial mapping and scientific research. New technology allows UAVs to plot their own route without human intervention.

**Phones & tablets**
The most obvious bit of AI technology in your smartphone or tablet is in the camera. Facial recognition, allowing for easier focusing and tagging, is a real leap forward in intelligent image-capturing technology.

**Advanced toy robots**
Created by Aldebaran, NAO is an advanced humanoid robot. It can walk on a variety of surfaces, recognise images and faces, work out who is talking to it, and even play Noughts and Crosses (Tic-Tac-Toe).

## Inside a GPU

One of the key ways that robots are able to catch up with humans in terms of raw processing power is by taking advantage of graphics processing units (GPUs). These computer chips are able to deal with more than one task at a time and cope with much bigger data sets than the central processing unit (CPU) that, until now, has been the standard command centre in robots and PCs. If you think of a computer like a rowing boat, the CPU is the cox (the brains of the outfit), while the GPU is the rowing force, providing the raw power to take the load off the cox. CPUs have a small number of cores, designed for sequential tasks, while GPUs have thousands of smaller cores so each can be put to work sifting through data at once.



**Processor fan**
The sheer number of cores running simultaneously creates a lot of heat, so a large fan is required for cooling.

**Memory**
Information is stored here, allowing the GPU to process multiple pieces of data at once.

**Transistors**
The more transistors, the more power can be transferred around the circuit board. Therefore, GPUs boast a lot more transistors than CPUs.

**Motherboard connection**
This is where the GPU is linked to the machine's mainframe.

## AI in videogames

As many gaming devices now use GPUs as their processing chip, videogames are able to make use of the increased power and human-like thinking of NPC protagonists and antagonists. *Alien: Isolation* by Creative Assembly revisits the *Alien* film franchise and has you play as Ripley's daughter Amanda, trying to escape from the alien on board the Sevastopol space station. The alien doesn't run along a predetermined path, instead reacting to the player's behaviour. Not only that, but it learns whether you are a 'hider' or a 'runner'. The advanced game engine has the ability to make instantaneous decisions, thanks to a GPU that can make a lot of decisions at once, rather than rely on the CPU to make a series of linear decisions.

Also making the most of AI technology are fighting games like *Tekken 5: Dark Resurrection*. In the Yurin Dojo, you are able to battle a 'ghost character' in which you fight an opponent based on the combat style of another player. All the time you are playing the game, it gathers info about your fighting style in order to re-create you as one of the in-game characters!

AI tech in *Alien: Isolation* allows the enemy to adapt to your gameplay strategy

this other thing?' Robots are much smarter than us. They can perform logic and mathematical tasks much quicker. However, we can go from observing sequences in the world and build representations of them in our brains. This is what we are now trying to achieve with AI."

De Freitas is heavily involved with the development of Deep Learning, a programme which looks to replicate the human brain's ability to not only see an image but understand it as well – something major technology corporations like Google, Amazon and Facebook are keen to exploit.

"Deep Learning tries to get robots to build representations of the world and operate on those representations to build sequences in their mind. Then we want them to learn to construct different sequences. It's like if you take all the videos on YouTube, cut each video into ten-frame chunks and cut and paste them into new movies. The next step is to imagine alternative scenarios to what is put in front of them. We want computers to learn abstract representation about their environment and then think about their environment and the cause and effect of their actions.

"All the big search engines already use this tech. For Facebook, that means learning about users from all the data they input. You can learn a lot from the data that exists out there – even their IQ. They could use this data to start recruiting, or even become a life coach. No psychologist has ever had access to this amount of data. I talked to Mark Zuckerberg about this a few months ago. There's a reason why he's investing in this."

Google is also taking a close interest in the possibilities AI brings to the table. The company's reported £242 million ($400 million) acquisition of DeepMind, a London-based AI company, and their hiring of notable AI pioneers Ray Kurzweil and Geoffrey Hinton shows that the big players are keen to exploit this emerging technology.

The Google Chauffeur is a self-driving car, which is creating waves in Silicon Valley where executives are testing them out on public highways. Google reports that its cars have collectively driven over 800,000 kilometres (500,000 miles) without a single accident. There were 1,754 fatalities on Britain's roads in 2012 and more than 33,000 in the United States, while a further 145,000 were injured on US highways. De Freitas says that in the near future "cars will be way better than humans at driving." Computers are able to react much quicker than people. Google Chauffeur is able to make hundreds of diagnostic checks per second and only requires serious human intervention every 58,000 kilometres (36,000 miles) on average. Considering that in the UK in 2012, the average distance a person travelled in a year was around 10,800 kilometres (6,700 miles), you would need to drive for five years before having to take any action!

Another near-future application for AI is in the medical industry. Two robots that are already operating in Japan are the RIBA robot, which can lift patients comfortably and take instructions from an operator, and the Actroid-F, a human-like bot that can act as an observer to nurses. But, according to De Freitas, robotic nurses could very soon become a reality. "Robots can do diagnoses much faster than us. Right now, we send patients, including elderly people, home and the nurse only visits every now and again. If you instrumented their home, making sure it was non-invasive, you could train a system to detect when a patient is about to have a lapse so you could send an ambulance in time. It's not something that's enabled yet, but there are a few companies that are working on it."

So artificially intelligent robots are more than capable of performing complex tasks. But what happens when they fall into the wrong hands? "Just as people can use AI in cars to help us drive to work, people can also use AI to drive around and kill people. As someone who works on it and sees it coming, this is a very legitimate concern.

"We already have a lot of aircraft that fly autonomously. It's not a technology of the future. It's here now, so I think there should be a Geneva convention-type agreement to stop people misusing robots. But no, I don't see AI robots rising up and destroying us. If anything, I see them rising up to stop us killing each other.

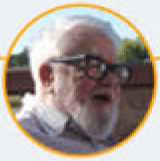
"The AI robot of the future will be an intelligent machine of a different kind, like a rat is different from a human. They won't be human, because what makes us human is different from what makes a piece of silicon human."

## KEY DATES
HISTORY OF AI

**1642**
French mathematician Blaise Pascal invents a device that helps his taxman father add and subtract numbers.

**1936**
Alan Turing invents the Turing Machine – a theoretical computer that follows a set of directions.

**1956**
The first recorded use of the term 'artificial intelligence' is by John McCarthy, proposing a conference on the subject.



**2011**
IBM's Watson defeats humans in gameshow *Jeopardy!*, requiring unprecedented levels of speech recognition and hypotheses.

**2012**
Google executives begin testing self-driving cars on public highways.

**DID YOU KNOW?** *In 2012 a Brazilian researcher estimated that the average human brain has around 86 billion neurons*

# Humans vs robots

**Who comes out on top in the battle of the brains?**

### VERDICT

**Humans still edge the battle of the mind on multilayered matters, such as forward planning, meaning that creative and on-the-spot thinking are still our forte.**

### ✓ Planning
This is where humans really trump computers. Humans can map out a series of sequences to lead us to a goal. Involving millions of neurons interacting in yet fully understood ways, computers lack this ability for now.

### Logic ✓
Computers are extremely linear when it comes to thinking. Because of this – as well as their lack of emotional responses – they can work logically through commands to reach the best possible solution.

### ✓ Speech recognition
Computers are catching up, but humans still have the edge. Most humans can hear a sentence and extract meaning from it, based on experience and the situation. Few robots are able to do this, though natural language processing, like the iPhone's Siri technology, is constantly improving.

### Maths ✓
There's no denying it, computers are geniuses when it comes to doing sums. Just ask your calculator. Again, because base mathematics is the input of data and the extraction of a single solution, a simple programme can work through calculations extremely quickly.

### ✓ Adapting
Most computers are programmed in a certain way and are only able to react to what they have been taught. Humans have the ability to think creatively about a subject, due to our evolved neocortex, and come up with radical, outside-the-box solutions. Until roboticists are able to replicate the neural connections, we will stay ahead of robots when reacting to novel situations.

### Speed ✓
Computers are able to operate at much faster speeds because they are stripped-down basic brains. Just think, even though a Land Rover may have more horsepower than a Ferrari, the latter is faster because it has less weight to hold it back. Similarly, when put to a task, a computer is able to work through a problem quicker, despite a human brain having more processing power.

### VERDICT

**There is simply no matching robots when it comes to pure logic and mathematical problems. If you want to work something out quickly and accurately, ask a robot.**

## Future AI tech

**Self-driving cars**
As yet only allowed to be driven in California and currently undergoing testing, this Google driverless car is an exciting pioneer that could herald a new era of transport, using advanced diagnostic tools to look out for hazards.

**Robot medics**
Machines could keep a watchful eye and run analysis on vulnerable patients faster and with greater accuracy. A trial is currently running at the Memorial Sloan-Kettering Cancer Center in New York, advising on lung cancer treatment.

**Space vehicles**
Work is progressing on space vehicles with 'human-like brains' that can plot their own route on treacherous planets like Mars by constantly analysing the terrain and making creative decisions, running off GPUs rather than CPUs.

© Alamy; SPL; Aldebaran Robotics; Thinkstock

# Inside the OUYA

## Meet the open-platform console which lets you play your videogames on a system that was designed to evolve

The OUYA is a videogame console that runs on a custom version of the Android 4.1 Jelly Bean operating system. Unlike many existing games consoles, however, the development of this machine was achieved through crowd-sourced funding, with the maker – OUYA, Inc – raising a whopping $8.5 million (£5.6 million) in 2012. Breaking from the norm, the OUYA has been designed as an open platform, with the device capable of being modified easily by owners.

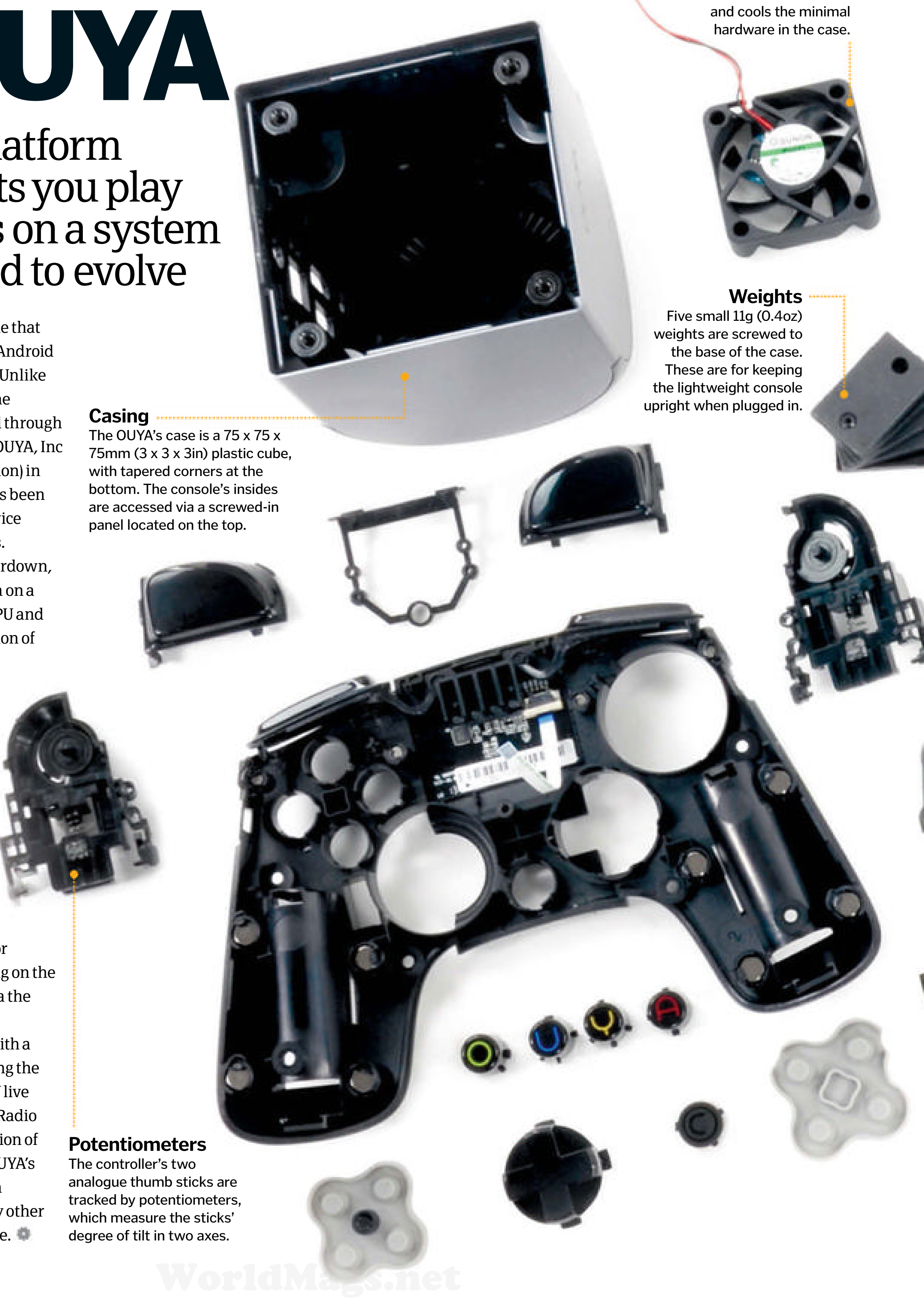
As can be seen in greater detail in the teardown, the OUYA runs off an NVIDIA Tegra 3 system on a chip, which combines the console's CPU, GPU and memory. This, in partnership with a selection of mainboard ports and connectivity chips – including Wi-Fi and Bluetooth – allows the OUYA to be connected to a television or computer and run its own custom user interface (UI) off the Jelly Bean OS.

Key to the OUYA's UI is the OUYA store, which is the main conduit to the console's selection of games. Indeed, as the system has no physical media, all titles are installed on the console's storage drive (eight gigabits internal; expandable via USB or digital download). The majority of games currently available or confirmed are ports of titles already existing on the Android marketplace. Games are played via the OUYA's own Bluetooth-linked control pad.

The gaming side of things is combined with a host of media-related applications, including the open-source XBMC media player, TwitchTV live videogame stream broadcaster and iHeartRadio internet radio platform. Along with a selection of videogame emulators this completes the OUYA's stock package, but due to the system's open hardware and software architecture, many other applications and services are in the pipeline.

## The next-gen gamer

**Take a look at the major components inside this cutting-edge gaming system**



**Fan**
A Sunon MagLev DC brushless fan is fixed to the mainboard's heatsink. This is rated for 12V at 0.8W and cools the minimal hardware in the case.

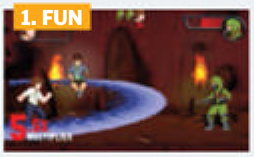
**Weights**
Five small 11g (0.4oz) weights are screwed to the base of the case. These are for keeping the lightweight console upright when plugged in.

**Casing**
The OUYA's case is a 75 x 75 x 75mm (3 x 3 x 3in) plastic cube, with tapered corners at the bottom. The console's insides are accessed via a screwed-in panel located on the top.

**Potentiometers**
The controller's two analogue thumb sticks are tracked by potentiometers, which measure the sticks' degree of tilt in two axes.

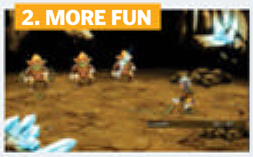
## HEAD 2 HEAD
OUYA GAMES

**1. FUN**



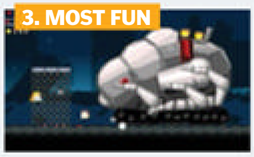
### Saturday Morning RPG
An old-school RPG with an Eighties cartoon look, *Saturday Morning RPG* is an episodic title that was community funded too.

**2. MORE FUN**



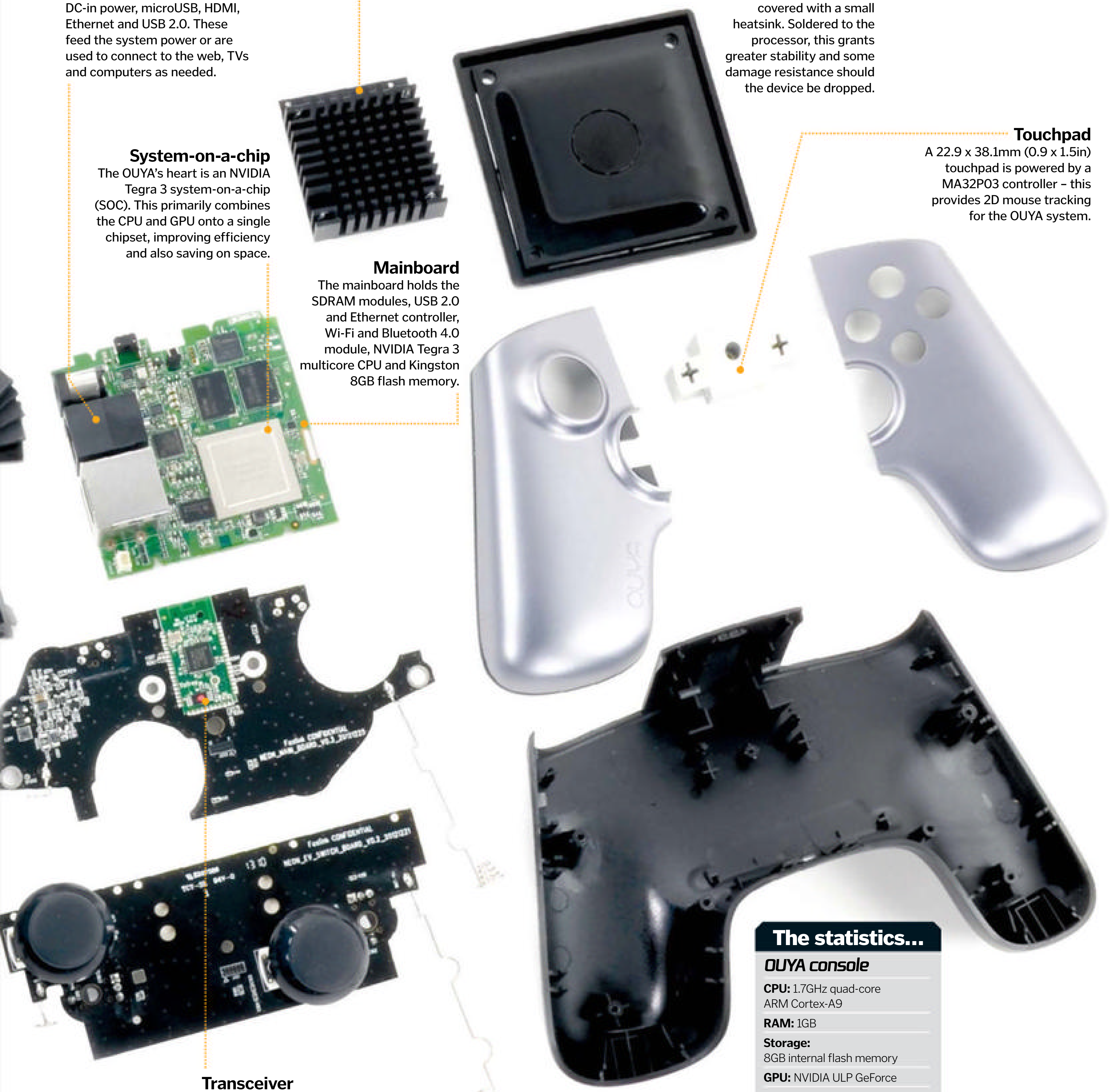
### Final Fantasy III
The Nineties classic, remade in full 3D in 2006, gets a fantastic port on OUYA, with new story sequences and improved visuals across the board.

**3. MOST FUN**



### Gunslugs
A hectic 8-bit-style, side-scrolling shooter, *Gunslugs* is a pleasure to play and captures the Eighties arcade gaming scene with aplomb.

**DID YOU KNOW?** *The OUYA's development was funded by the public in just eight hours*



### Ports
The OUYA has five ports: a DC-in power, microUSB, HDMI, Ethernet and USB 2.0. These feed the system power or are used to connect to the web, TVs and computers as needed.

### Heatsink
The system-on-a-chip is covered with a small heatsink. Soldered to the processor, this grants greater stability and some damage resistance should the device be dropped.

### Touchpad
A 22.9 x 38.1mm (0.9 x 1.5in) touchpad is powered by a MA32P03 controller – this provides 2D mouse tracking for the OUYA system.

### System-on-a-chip
The OUYA's heart is an NVIDIA Tegra 3 system-on-a-chip (SOC). This primarily combines the CPU and GPU onto a single chipset, improving efficiency and also saving on space.

### Mainboard
The mainboard holds the SDRAM modules, USB 2.0 and Ethernet controller, Wi-Fi and Bluetooth 4.0 module, NVIDIA Tegra 3 multicore CPU and Kingston 8GB flash memory.

### Transceiver
A Broadcom Bluetooth 3.0 transceiver features an integrated ARM Cortex M3 processor. This receives all inputs from the controller and transmits them to the OUYA.

### The statistics…
*OUYA console*

**CPU:** 1.7GHz quad-core ARM Cortex-A9

**RAM:** 1GB

**Storage:** 8GB internal flash memory

**GPU:** NVIDIA ULP GeForce

**Dimensions:** 75mm (3in) a side

**OS:** Android 4.1 Jelly Bean

**Cost:** Under $99 (£99)

© iFixit.com

The SB60 airSOUND BASE

# Surround sound evolved

## How does this modern speaker deliver spatial surround sound out of one box?

The SB60 airSOUND BASE from Orbitsound is a new breed of soundbar, an all-in-one speaker system that combines multiple loudspeakers, a subwoofer and a series of amplifiers and electrical systems into one thin box. What differentiates this unit from previous soundbars, though, is the inclusion of both a low-frequency speaker within its case – where traditionally soundbars have come with a separate subwoofer – and secondly, a unique airSOUND audio processing unit.

The airSOUND processor works by taking an audio recording's left and right electronic surround-sound signals, then separating and processing them into a 'main' and 'spatial' signal. The former is the recorded signal in its entirety, while the latter is the left and right signals with any common information filtered out. Common information includes any elements of the two signals that are identical, so in removing them each spatial signal only transmits the differences in the audio track, making for better sound quality and less distortion as caused by wave cancellation.

The included subwoofer – technically a low-frequency loudspeaker, as it produces audible frequencies too – is possible thanks to the vacuum-sealed, resin-bonded casing of the SB60. Indeed, the subwoofer and all four loudspeakers are located in their own sealed, irregularly shaped compartments to minimise acoustic reverberations and oscillations. The sub is placed in two compression zones that help it deliver bass frequencies without rattling in the box and surface it sits on.

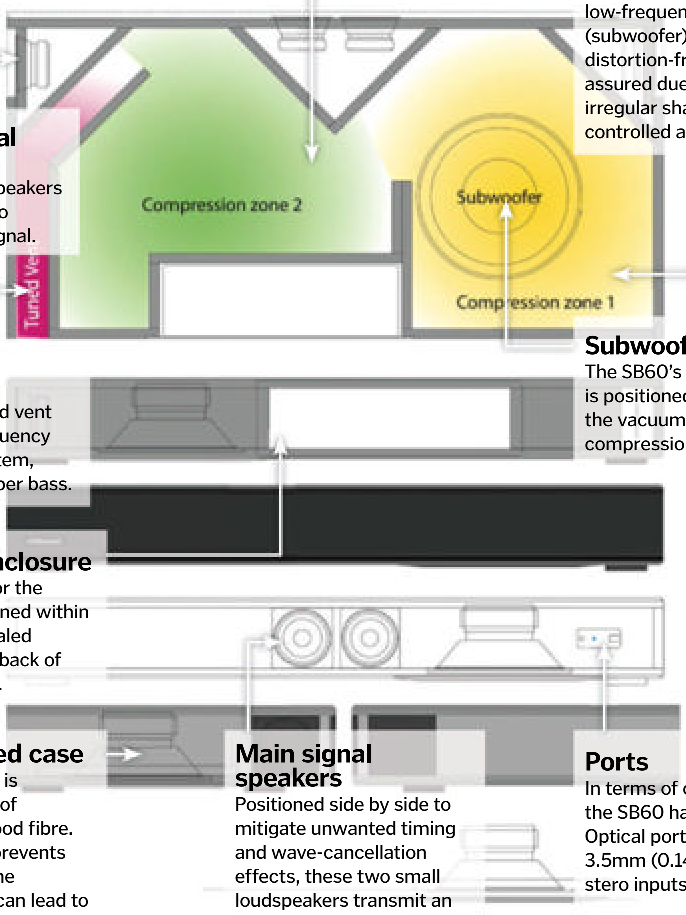
Combined, the airSOUND spatial surround sound and integrated sub allow the SB60 to re-create an audio track's sound picture – the original position and timing of all the track's sounds – without requiring a number of traditional floor-standing speakers.

## THE STATS
**SB60 FIGURES**

WIDTH 600mm
POWER OUTPUT 200w
CROSSOVER FREQUENCY 220Hz
MAX SOUND PRESSURE LEVEL (AT 1M) 95dB
HEIGHT 80mm
SPEAKERS 5

**DID YOU KNOW?** *The SB6o can be synced via Bluetooth to smartphones and tablets*

## SB60 up close
**How It Works takes a look inside this revolutionary new sound system**



**Spatial signal speakers**
Two small loudspeakers transmit an audio track's spatial signal.

**Compression zones**
The compression zones within the SB60 ensure the low-frequency speaker (subwoofer) produces distortion-free base. This is assured due to their irregular shape and controlled air volume.

**Tuned vent**
The SB60's tuned vent extends the frequency range of the system, allowing for deeper bass.

**Subwoofer**
The SB60's subwoofer is positioned within the vacuum-sealed compression zone one.

**Amplifier enclosure**
The amplifiers for the SB60 are positioned within a rectangular sealed enclosure in the back of the unit's casing.

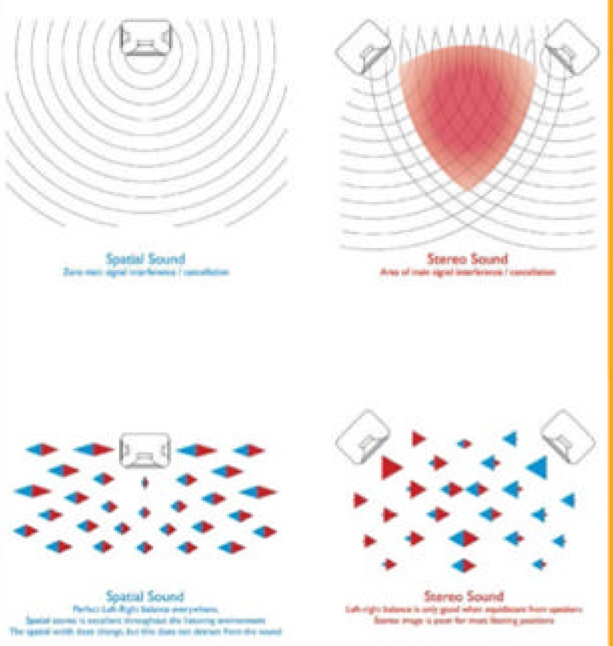
**Resin-bonded case**
The SB60's case is constructed out of resin-bonded wood fibre. The sealed box prevents leaks between the enclosures that can lead to audio defects.

**Main signal speakers**
Positioned side by side to mitigate unwanted timing and wave-cancellation effects, these two small loudspeakers transmit an audio track's main signal.

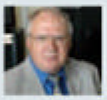
**Ports**
In terms of connections, the SB60 has a S/PDIF Optical port and two 3.5mm (0.14in) minijack stereo inputs.

## Spatial vs stereo sound

Because of the way the audio signal is treated in the SB60's airSOUND processor, the left-right input of an audio track is converted to a main and a spatial signal: the main signal being everything in the whole recording, while the spatial signal is just the bits that tell a user's ears/brain where things are (ie the sound's direction). Now, as when two stereo speakers reproduce a sound source they are merely playing the main signal from two separate sources, there are timing errors and areas of distortion, both of which lead to a poor audio experience. By splitting off these directional cues and transmitting them through the side speakers, the spatial quality of the original recording is maintained to a far higher degree, so a more natural sound is generated.


Spatial Sound
Zero main signal interference / cancellation
Stereo Sound
Area of main signal interference / cancellation
Spatial Sound
Perfect Left-Right balance everywhere.
Spatial stereo is excellent throughout the listening environment.
The spatial width does change, but this does not detract from the sound
Stereo Sound
Left-right balance is only good when equidistant from speakers
Stereo image is poor for most listening positions

## Man behind the SB60



**We speak to the SB60 designer, Ted Fletcher, to find out what technology makes this soundbar so special**

**Tell us about the development of the SB60.**
Recently there has been a shift in the industry where people have begun to say, "Why do we need a subwoofer in a sound system? It's large and takes up space in the corner of a room, and we don't like it." So the technical guys and I started to think if there was a way that we could incorporate bass frequencies into a small unit. We ended up deciding to stand the television on top of a very thin large speaker box and incorporate everything into it. We then built 20 prototypes perfecting the system – the result was the SB60.

**So, how does the SB60 work?**
The basis for the technology is that you have a main signal and a spatial signal. What we have done with the SB60 is that the main signal is generated by two small 45-millimetre (1.8-inch) loudspeakers positioned side by side at the front of the SB60. These speakers are in their own enclosure, which is triangular so the acoustic reflections inside the enclosure don't bounce backwards and forwards off parallel surfaces. This improves audio performance massively.

The spatial signals, which are responsible for telling your ear where things are, are generated by two small loudspeakers positioned on the sides of the unit. Again, these speakers have their own triangular enclosures to minimise the negative effects of acoustic oscillations.

The whole thing is constructed out of resin-bonded wood fibre and is super high-density. The box is bonded together to prevent leaks between the enclosures. This is necessary, as each compartment needs to be acoustically separated to be effective. That is why the SB60 is vacuum-sealed, because if you have any leaks at all you get unwanted hissing noises from the high pressure built up within the loudspeakers.

Now we come to the interesting bit: the bass frequencies. We don't technically have a subwoofer in the SB60; it is more of as low-frequency speaker, as the frequency that it crosses over at is around 200 Hertz, so it does audible frequencies too. Anyway, that is mounted very rigidly inside the box, and behind it you have a large compression zone, which is split into two. The reason why the compression zone is split is because the second zone's irregular shape does a very good job in loading the back of the speaker without there being any nasty oscillations. Finally, there is a tuned vent at the back of the compression zones, which helps make the frequency range even lower.

**Why is the SB60 better than any other soundbar available?**
All other soundbars produce sound from their loudspeakers that is very similar. The speakers are also all separated in space by more than a couple of feet. With those setups you get interaction between the loudspeakers, wave cancellation effects in the air and distortions.

© Orbitsound

# The 3Doodler

## How does this pen let you draw in the air?

The world's first 3D-printing pen – WobbleWorks's 3Doodler – was launched on KickStarter in 2013, where it received over £1.3 million ($2 million) in funding in just 34 days. This gizmo enables you to turn drawings into full-3D models on any surface, without the need of any software or computer. Unlike a normal pen, however, the 3Doodler doesn't use ink, instead relying on filaments of ABS or PLA plastic, materials also used by most desktop 3D printers.

Similar to its more expensive desktop counterparts, the 3Doodler prints by heating three-millimetre (0.1-inch)-thin strands of plastic, which need to be loaded into its back. After turning the 3Doodler on and waiting a few minutes for it to warm up, the LED indicator light will then turn blue, which means that the heated plastic can then extrude from the 3Doodler nozzle's metal tip – the only potentially dangerous part, which can get as hot as 270 degrees Celsius (518 degrees Fahrenheit).

Once the heated plastic leaves the nozzle, it quickly solidifies into a strong, stable structure, allowing you to build shapes with ease. Because the heated plastic can be drawn over almost any surface, including other plastic, even items like an iPhone case can be personalised in a variety of colours. There are two temperature settings so users can switch between the different melting points of ABS and PLA, and two main speed control buttons allow for the heated plastic to flow quicker or slower. This makes it possible to create large items with a sizeable area to fill, as well as more intricate, delicate details.

The 3Doodler allows anyone to draw straight into the air by heating ABS or PLA plastic

### 3Doodler 2.0

The new update to the original 3Doodler is the latest 3Doodler 2.0, which is 75 per cent smaller and more than 50 per cent lighter than the first 3Doodler at only 50 grams (1.8 ounces).

Enhanced airflow from the top of the pen allows for plastic to be kept cool more quietly and efficiently while requiring less than half the power, while a new manual temperature optimisation option lets artists control minor flow adjustment to their extruded results.

The nozzle has also been redesigned to improve accuracy, and a fully re-engineered drive system, including the option for both speed control and a double click for continuous flow, has been added.

### The difference between ABS vs PLA for 3D printing

One of the most common plastics around today is ABS, or Acrylonitrile Butadiene Styrene. Made of oil-based resources, it's much stronger and less likely to snap when bent compared to PLA, and has a higher melting point at 225 to 250 degrees Celsius (437 to 482 degrees Fahrenheit) for the 3Doodler. It forces out a more flexible material from the pen, and is easier to peel off of paper than the 3Doodler PLA. In traditional 3D printing, ABS is a plastic that can easily deform if not being printed on a heated surface, such as a heated build platform.

PLA, or polylactic acid, is a biodegradable polymer, so it is considered better for the environment when properly recycled compared to ABS. It also comes in a huge variety of colours and can even be translucent. However, due to the lower melting point of 190 to 240 degrees Celsius (374 to 464 degrees Fahrenheit) for the 3Doodler, PLA is more prone to overheating and can droop if it gets too hot. It also adheres very well so may not be suitable for peeling off paper like ABS is; though this is an advantage for mixed media, such as sticking 3Doodle creations to a glass surface.

Both PLA and ABS can be used with the pen, which heats at two different temperatures

**THE STATS**
**XPERIA Z ULTRA**

| | |
|---|---|
| DIMENSIONS | 179x92x6.5mm |
| CPU | 2.2GHz quad-core |
| WEIGHT | 212g |
| DISPLAY | 1,920x1,080px |
| BATTERY | 3,000mAh |

**DID YOU KNOW?** *The first commercial waterproof mobile phone was the LG CanU 502S released in 2005*

# Waterproof smartphones

## How do these electronic devices carry on working even when underwater?

Today there are two main methods for waterproofing a smartphone: physical barriers such as port covers and sealed seams that prevent liquid entering externally, and nanocoatings that penetrate the device entirely and actively repel water. While both techniques are used, the most effective is the latter, enabling devices to be water resistant without compromising on size and aesthetics.

There are different types of nanocoating, but one of the most commonly used is that made by P2i. This company's waterproofing process involves subjecting any electronic gizmo to a plasma-enhanced vapour in a vacuum chamber at room temperature. The vapour contains a gaseous polymer, which when brought into contact with the device's surfaces – both external and internal – forms a super-strong covalent bond and waterproof barrier 1,000 times thinner than a human hair.

Once on the phone, the ultra-thin polymer layer then dramatically reduces its surface energy, forcing any water that comes into contact with it to bead up and be repelled.

Simply put, the coating acts in a similar way to the waxy feathers on a duck's back, preventing water from infiltrating the top layer and forcing it to run off the sides. Obviously, in the case of a smartphone, this action would prevent water from penetrating the delicate internal components. However, due to the vapour disposition process, even if water were to penetrate the mobile's casing, each internal component would also be coated with the polymer, protecting them until the water evaporated or was dried off manually.

## A phone worth splashing out on

We pick out the key components that keep the Xperia Z Ultra super-dry

**Port covers**
Each port on the Z Ultra comes with a protective cover. These prevent water entering while submerged.

**Tough materials**
Thanks to a hardened glass front and back covers, plus encircling metal frame, the phone can remain underwater for up to 30 minutes.

**Depth**
As the Z Ultra is IP55/IP58 certified, it can be submerged in up to 1.5m (4.9ft) of freshwater without risk of damage. It is also protected from low-powered jets of water.

## Waterproof phone rivals

**1 Motorola Defy**
With a single-core 800MHz CPU, 512MB of RAM, a 1,540mAh battery and a small 9.4-centimetre (3.7-inch) screen, the Defy is very much an entry-level water-resistant phone.

**2 Samsung Galaxy S4 Active**
With a quad-core 1.9GHz Snapdragon CPU, 2GB of RAM and Android 4.2.2 installed, the S4 Active is a decent-spec, good all-round smartphone that can take the plunge.

**3 Sony Xperia Z Ultra**
With a huge 16.3-centimetre (6.4-inch) screen, 2.2GHz quad-core CPU and 8MP camera, the Z Ultra is by far the largest and highest-spec waterproof phone on the market to date.

© Sony; Samsung; Robot8A

# Electric guitars

## What technology lends these iconic instruments their distinctive sound?

The electric guitar is probably the defining sound of 20th-century music. Like all good inventions, it solved a problem: in a band with several instruments, guitars were too quiet. In the Thirties, several guitar manufacturers developed the magnetic pick-up, which fitted underneath strings and fed an electric signal to an amplifier.

Modern guitars work in exactly the same way. Strings are made from ferromagnetic metal, usually nickel or steel. The pick-up is a bar magnet housed inside thousands of turns of wire. The vibrating strings cause fluctuations in the magnet's field, which in turn induces an alternating current in the wire. This current is the signal which is carried to the amp. Electric guitars can have a single pick-up for all the strings or one for each string.

Guitars could be heard, but the audience heard something else too: horrible howling feedback. The hollow body of the first electric guitars vibrated with sound waves from the amp, so this second problem was solved by introducing a solid body.

There is a fierce ongoing debate around who created the first solid electric guitar, but the most popular and widely sold early model was the Fender 'Broadcaster' (later called 'Telecaster'), followed in 1954 by the company's legendary 'Stratocaster'.

Manufacturers have tried making plastic, aluminium, twin-necked and headless guitars – even 'synth' guitars with MIDI (musical instrument digital interface) technology. But for the most part guitarists prefer the original; they might dabble for a while, but they always go back to the traditional six-string design.

While amps, MIDI and USB systems have all improved, providing better ways to record and enhance music, the electric guitar itself is fundamentally the same as it was in the Fifties – a testament to its well-conceived design.

### Acoustic vs electric

All guitars have a body, neck and strings. Electric guitars need ferromagnetic metal strings while acoustic guitars can use strings made from nylon, bronze, brass or metal-wrapped nylon. Both acoustic and electric guitars are usually made of wood. Wood is ideal because it's relatively cheap, light and easy to shape – not to mention the fact that it also lends guitars their distinctive warm sound.

The main difference between the two types of guitar is how they produce sound. The hollow body of an acoustic guitar provides a big chamber for air to reverberate. Pluck a string and the vibration travels through the bridge into the body. The body and air inside it vibrate, creating compressed sound waves. For an electric guitar, you need an amp (or computer) to produce sound worthy of being called 'music'.

### Amp up the volume

Amps boost the input signal from the guitar and drive the speaker cone. Plugged in, the weak fluctuating signal from the pick-ups passes through a series of transistors, modifying the amp's DC circuit. Next the vibrating cone generates sound waves, replicating and amplifying the sound produced by the strings.

When vacuum tube amps were replaced by solid-state amps in the Seventies, guitarists complained they sounded 'colder'. Modern amps often combine the two types for a warm but loud sound, and if your computer has a fast enough processor, you can use it as a virtual amp.

**RECORD BREAKERS**
**GUITAR GOLIATH**

# 907kg

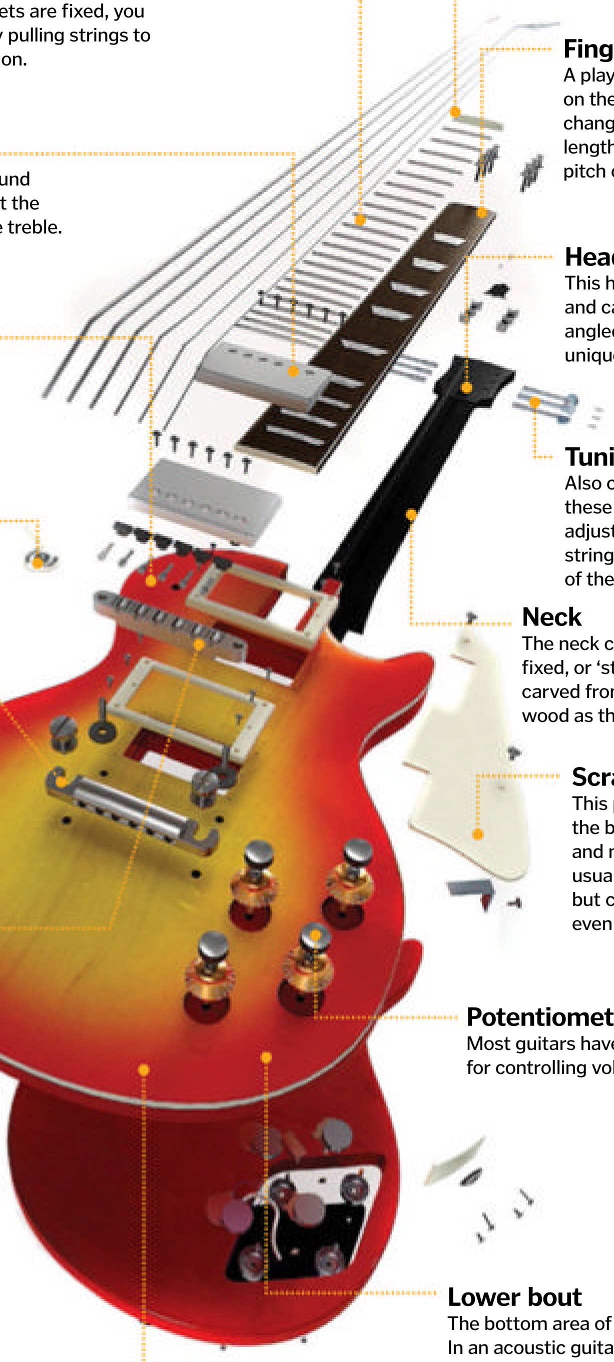
## LARGEST PLAYABLE ELECTRIC GUITAR

School students in Conroe, Texas, made a 12:1 scale version of a 1967 Gibson Flying V. It stands 13.3m (43.6ft) tall, 5m (16.4ft) wide and weighs 907kg (2,000lb). It was first played in public in June 2000.

**DID YOU KNOW?** *Amazingly, Leo Fender – manufacturer of the famous 'Stratocaster' – couldn't play guitar*

# Teardown of an electric guitar

**What are the major components of these amazing instruments?**



**Fret**
The thin, raised metal bars across the fingerboard. The distance between frets corresponds to one semitone (12 semitones make up one octave). The first fret is the one nearest the nut. Although frets are fixed, you can change a note's pitch by pulling strings to one side to change the tension.

**Pick-ups**
Nearest the neck, the tone of the sound picked up here is more bass, while at the bridge the tone of the sound is more treble.

**Upper bout**
The top area of the body. In an acoustic guitar, this area produces the treble sounds.

**Pick-up selector**
This selects which pick-ups send signals to the amp. For a guitar with two pick-ups, the switch positions are: neck, bridge and both together.

**Saddle tailpiece**
This can be adjusted to change string length and therefore tone.

**Bridge**
Holds the strings away from the body. The strings may terminate here or just pass over it. The height of the bridge can also be modified with screws.

**Strap button**
One on the upper bout and one under the body. Many guitarists prefer locking straps, which prevent them from coming adrift mid-performance.

**Body**
Usually kiln-dried hardwood (mahogany, ash, walnut, etc), the heavy body prevents unwanted vibrations.

**Nut**
This holds the strings in their right places and feeds them into the tuning pegs. You can lubricate the grooves in the nuts with graphite from a few swipes with a pencil.

**Fingerboard**
A player can press down on the strings here to change the vibrating length and therefore the pitch of the note.

**Headstock**
This holds the strings and can be flat or angled. The shapes are unique to each model.

**Tuning pegs**
Also called machine heads, these can be twisted to adjust the tension on the string, changing the pitch of the note it produces.

**Neck**
The neck can be adjustable or fixed, or 'straight-through' – carved from the same piece of wood as the body.

**Scratchplate**
This protects the finish of the body from plectrum and nail scratches. It's usually made of plastic but can be glass, wood or even fabric.

**Potentiometers**
Most guitars have at least two pots for controlling volume and tone.

**Lower bout**
The bottom area of the body. In an acoustic guitar, this part produces the bass sounds.

## Jargon buster

**Pick-up**
A bar magnet wrapped in a coil of wire. Vibrations in the strings cause vibrations in the magnetic field, which induces a current in the wire.

**Headstock**
Aka a 'peg-head', this holds the strings under tension.

**Cutaway**
This indentation in the body near the neck allows the player easier access to the upper frets. There are two types: the rounded Venetian and more pointy Florentine.

**Wah-wah pedal**
This pedal controls the bass and treble. It's pushed down to emphasise treble and left up for bass. To get the 'wah-wah' sound, you just have to rock it up and down.

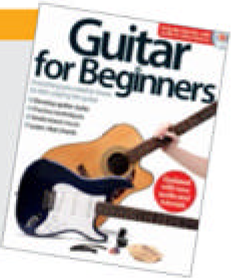
**Potentiometer**
A variable resistor used to adjust volume or tone. Knobs on guitars and amps are commonly called 'pots'.

**Passive/active**
Most electric guitars don't require electric power (only the amp) so are 'passive'. Some, however, do use power (from a battery or USB) to create effects, so are 'active'.

**Licks/riffs**
Licks are short musical phrases played in a solo. Riffs are short melody phrases which are repeated.

*Learn more*

If you've recently started playing the guitar, **Guitar for Beginners** is full of tips and tutorials. Check it out at **bit.ly/1iOVqQ8**.



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# SUPER COMPUTERS

## THE FASTEST & MOST POWERFUL COMPUTERS ON EARTH

- 15 YEARS OF CALCULATIONS IN ONE SECOND
- 83,000 PROCESSORS
- AS POWERFUL AS 715,000 iPADS

If you gave everyone in the UK a calculator and set them doing sums at the rate of one every second, it would take 15 years of combined, non-stop calculation to manage what the fastest supercomputer in the world can do in just one second. And yet the basic chips that power this mathematical monster are virtually the same as the CPU in your home PC.

The first supercomputers were built just as vacuum valve technology was beginning to be replaced with transistors. Manchester University installed one of the very first in 1962; a machine called Atlas. This computer had as much processing power as every other computer in the UK combined. In the USA, a company called CDC dominated the market for supercomputers for most of the 1960s. The CDC 6600 was ten times faster than its nearest competitor and the company sold 100 of them for $8 million each. The genius behind these computers was a man called Seymour Cray. When Cray left to form his own company in 1972, the supercomputer business jumped up a gear. The Cray-1 was the first to use integrated circuits (computer chips) instead of separate transistors. A lot of its speed came from a

## 5 TOP FACTS
FASTEST COMPUTERS

**Tianhe-2 – 33,863 Tflops**

1 Tianhe means Milky Way. 1,300 scientists and engineers collaborated to build it. There are 3,120,000 computing cores altogether, occupying $720m^2$ ($7{,}750ft^2$) of floor space.

**Titan – 17,590 Tflops**

2 Housed in 200 cabinets, Titan uses 8.2MW of power - as much as 2,000 private households. The cooling fans are so loud that staff have to wear ear protection.

**Sequoia – 17,173 Tflops**

3 It has modelled the electrical activity of the human heart and simulated 3.6 trillion stars in the cosmos. Sequoia was the first computer to use a million cores at once.

**K Comp – 10,510 Tflops**

4 Named after the Japanese word 'kei' which means ten quadrillion, in 2011 the K Computer became the first in the world to exceed 10,000 Tflops in size.

**Mira - 8,587 Tflops**

5 Based at the Argonne National Laboratory, outside Chicago. In one day it can perform as many calculations as a desktop computer would manage in 20 years.

**DID YOU KNOW?** *The USA is home to 233 of the top 500 supercomputers. China has 76, the UK has 30*

technique known as vector processing. It exploits the fact that most supercomputer applications run the same few calculations over and over across a huge dataset stored in memory. Traditionally, computers would fetch the first datapoint from memory, perform all the calculations, write the result back to memory and then fetch the next datapoint and repeat the entire process. The Cray-1 treated the operation like a factory assembly line, continuously feeding in data at one end and writing it back out at the other end. This ensured all circuits were busy all the time, instead of spending a while waiting for the next piece of data. The Cray-1 was ultimately succeeded by the Cray-2 in 1985, which remained the fastest computer in the world until 1990.

Vector processing depends on your ability to move data rapidly through the processor and most of the performance of the Cray-2 was simply due to the much faster memory chips it used. In the 1990s, supercomputer designers tried a different tack. Instead of having just a handful of processors (the Cray-2 had just eight) sharing a common pool of memory, they gave each processor its own private memory and arranged large numbers of them in a grid. Called mesh computing, this system connected each processor to its four immediate neighbours using network technology. When processors want to exchange data, they send it as a network message. Although this is slower than wiring the processors directly together, they can operate more independently and don't need to communicate as often. This makes the system much more scalable – you can make your supercomputer faster simply by adding more processors to the mesh.

Since 1993, the world's fastest supercomputers have been ranked at **www.top500.org** using a benchmarking program that measures computer speed as the number of floating-point operations per second, or flops. Floating-point operations are essentially maths calculations that involve numbers with a decimal point. If you could work out the answer to a sum such as 12.83224 x 619.113 in one second, your brain would be running at a single flop. Modern supercomputers are measured in teraflops (Tflops) or thousands of billions of flops. The ten fastest computers on the Top500 list are all petaflops machines – a staggering thousands of teraflops in size. And they might be getting faster still.

## Q&A: Dr Alan Simpson, technical director

### ARCHER's technical director reveals what the supercomputer's capable of

**ARCHER is the most powerful supercomputer in the UK, currently ranked 25th in the world. It's hosted at Edinburgh University and we spoke to Dr Alan Simpson, who is the technical director of the Edinburgh Parallel Computing Centre.**

**What is the supercomputer ARCHER primarily used for?**
ARCHER is used for materials and chemistry, engineering and environmental science. Example applications [for the supercomputer] include: longer-lasting smartphone batteries, quieter, [designing] more efficient aeroplanes and understanding climate change.

**How does it compare to its predecessor?**
ARCHER is capable of performing at least three times more computational research than its predecessor, HECToR.

**Why does Edinburgh need its own supercomputer?**
ARCHER is the national HPC [High Performance Computing] system for the United Kingdom and provides computational resources for nearly all the major UK research universities.

**How many people have access to ARCHER?**
ARCHER will have more than 3,000 users from more than 50 research institutions across the UK.

**How many simulations are running on it at any one time?**
Typically, more than 100 simulation jobs of varying sizes run at the same time, although some jobs take up the full system.

**How much space does ARCHER take up?**
ARCHER is made up of 16 cabinets, each of which is roughly the size of a wardrobe.

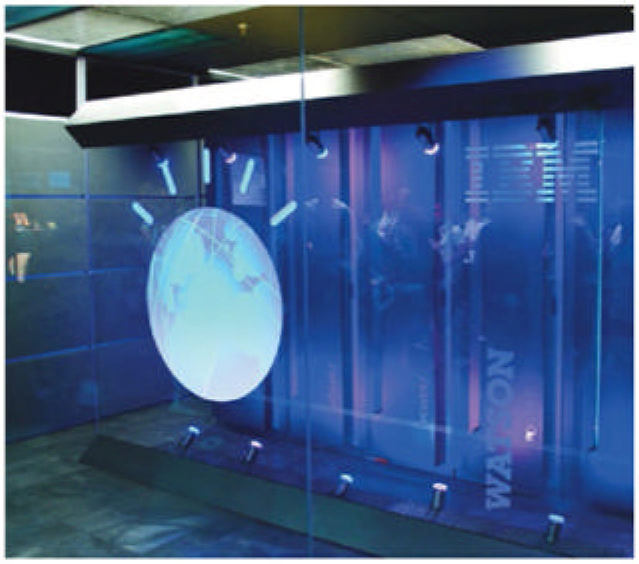
**How much electricity does it use to run and to keep it cool?**
It uses more than 1MW of electricity. ARCHER is housed in a specially designed building that minimises electricity used in overheads, particularly chilling. As Edinburgh has a cool climate for much of the year, we are able to exploit 'free cooling', ie passive cooling of water to the atmosphere.

**What is your role within the ARCHER project?**
I lead the teams providing science support and user support.

**How long is it expected to last before it is replaced with something better?**
The initial contracts for ARCHER are for four years. UK national HPC services typically last between four and eight years.

**How many staff are required to run and maintain ARCHER?**
There are two Cray engineers on site plus around five University of Edinburgh systems staff. There are also a significant number of staff involved in the service desk and in-depth computational science and engineering support.

**What operating system does it use?**
ARCHER uses Cray Linux Environment (CLE), a proprietary version of Linux.



Modern supercomputers now use tens of thousands of processors. The only way to build them cost effectively is to use off-the-shelf components – most of the ten fastest supercomputers in the world use high-end variants of the Intel processors in your desktop PC. The newest ones use the graphics processing units (GPUs) found on your computer's graphics card too, but they don't use them for running video games. GPUs are very good at vector processing and by combining a CPU and a GPU into a single computing unit, hybrid supercomputers are able to gain the advantages of vector processing and mesh computing at the same time. GPUs now account for about 90 per cent of the processing performance of the fastest supercomputers and allow them to run ten times as fast as the previous generation, while only consuming about twice the power.

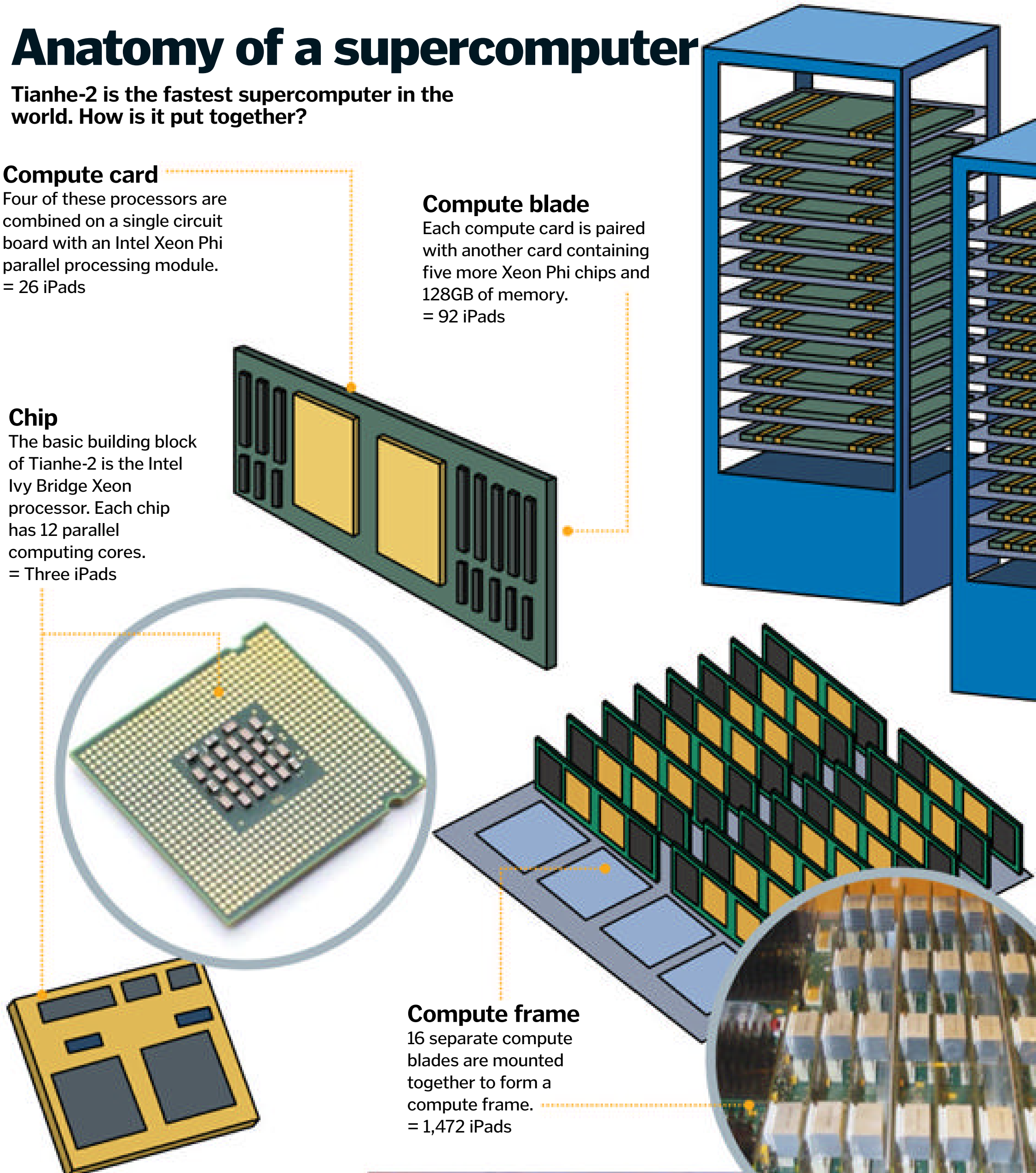
Supercomputer applications are written in the Fortran, C++ and Java programming languages, but programming massively parallel supercomputers is nothing like writing software for a Windows PC. In order to harness all the processors, you need to be able to break up your problem into smaller pieces that can be distributed among them.

If you are modelling the stars in the universe or the flow of air molecules over a turbine blade, you can't simply assign each processor to a different star or molecule because the calculations from one point in the simulation affect those around it.

The Global Address Space Programming Interface (GPI) is a new programming tool that allows each processor to treat all the memory on all the processors as a single shared pool. The GPI handles the work of sending the right messages to keep each processor up to date at all times, leaving the research scientist to get on with defining how the simulation should run, making the supercomputer more efficient.

## Anatomy of a supercomputer

**Tianhe-2 is the fastest supercomputer in the world. How is it put together?**



**Compute card**
Four of these processors are combined on a single circuit board with an Intel Xeon Phi parallel processing module.
= 26 iPads

**Compute blade**
Each compute card is paired with another card containing five more Xeon Phi chips and 128GB of memory.
= 92 iPads

**Chip**
The basic building block of Tianhe-2 is the Intel Ivy Bridge Xeon processor. Each chip has 12 parallel computing cores.
= Three iPads

**Compute frame**
16 separate compute blades are mounted together to form a compute frame.
= 1,472 iPads

## Getting access

If you want to run your simulation on one of the really big supercomputers you'll need to write a proposal. Once a year, a vetting committee checks whether the science value is justified and the computer code is free of bugs. Your program should need at least 20 per cent of the total power of the supercomputer; otherwise it could just as well run on a smaller supercomputer. If you are a research scientist, access to the supercomputer is free, but you'll have to publish the results for everyone to use. Private companies pay for each processor they use and for each hour the simulation runs.

An IT engineer configuring servers

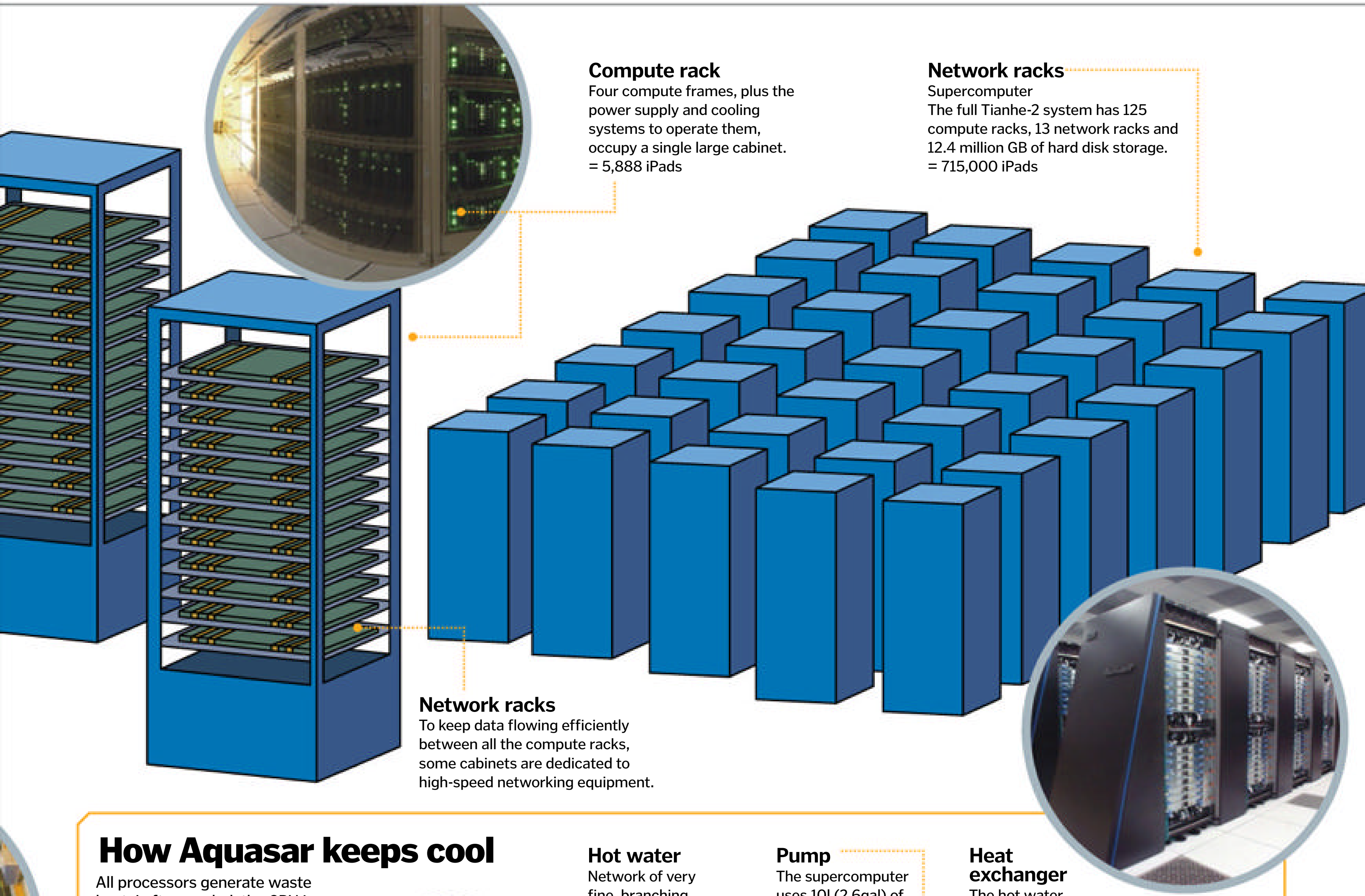
NASA's Discover Supercomputer has almost 15,000 processors

# 13 TRILLION

## LARGEST SIMULATION

The largest fluid dynamics simulation ever used 13 trillion simulation 'cells' to model the behaviour of 15,000 bubbles on the Sequoia supercomputer at Lawrence Livermore National Laboratory in the USA.

**DID YOU KNOW?** *The #3 supercomputer in the world, Sequoia, uses as much power as 2 million laptops!*



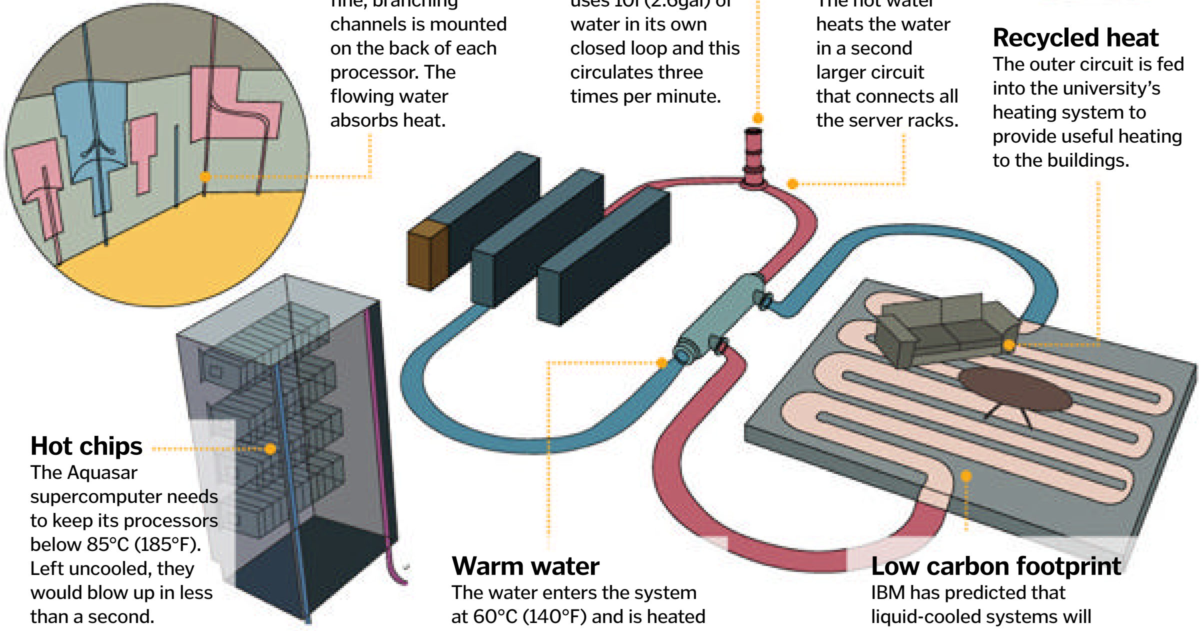
**Compute rack**
Four compute frames, plus the power supply and cooling systems to operate them, occupy a single large cabinet.
= 5,888 iPads

**Network racks**
Supercomputer
The full Tianhe-2 system has 125 compute racks, 13 network racks and 12.4 million GB of hard disk storage.
= 715,000 iPads

**Network racks**
To keep data flowing efficiently between all the compute racks, some cabinets are dedicated to high-speed networking equipment.

## How Aquasar keeps cool

All processors generate waste heat. Left uncooled, the CPU in your desktop computer would get dangerously hot and could damage components. To prevent this, the heat is dissipated through radiator fins, which are cooled with a fan. But in a supercomputer, blowing air fast enough over all the processors in all of the cabinets can be tricky. Water cooling is more efficient because it takes a lot more energy to raise the temperature of water than air, but water is conductible so it has to be contained within leak-tight cooling pipes. The new SGI ICE X supercomputer sidesteps this by using a fluorine-based coolant called Novec, which was developed by 3M. This fluid conducts heat well but is electrically insulating, so it can be pumped directly over live circuit boards. Cooling this way uses just five per cent of the electricity of air cooling and takes up ten times less space than water cooling.



**Hot water**
Network of very fine, branching channels is mounted on the back of each processor. The flowing water absorbs heat.

**Pump**
The supercomputer uses 10l (2.6gal) of water in its own closed loop and this circulates three times per minute.

**Heat exchanger**
The hot water heats the water in a second larger circuit that connects all the server racks.

**Recycled heat**
The outer circuit is fed into the university's heating system to provide useful heating to the buildings.

**Hot chips**
The Aquasar supercomputer needs to keep its processors below 85°C (185°F). Left uncooled, they would blow up in less than a second.

**Warm water**
The water enters the system at 60°C (140°F) and is heated to 65°C (149°F) while passing through the supercomputer.

**Low carbon footprint**
IBM has predicted that liquid-cooled systems will lower the carbon footprint by 85 per cent.

China, India and the USA are all committed to building an exaflops supercomputer by 2018. That's 1,000 petaflops, or about 30 times faster than the Chinese Tianhe-2 supercomputer, which is currently the world's fastest. Exaflops computing would allow scientists to finally model the human brain right down to a perfect simulation of each neuron, but the limiting factor right now isn't just money; it's electrical power. Tianhe-2 uses 24 megawatts of power. In the UK, the electricity bill for a machine this size would be over £21 million ($36 million) a year. Scaling this up to an exaflops supercomputer (1,000 petaflops) would require a large proportion of the output of a typical coal-fired power plant! However impressive the number-crunching abilities of supercomputers are, it seems they still can't match the energy efficiency of a brain. Maybe there's still a use for humans after all.

BO
TITAN
TITAN

A visualisation of a water droplet simulation performed by the Titan supercomputer for GE

The Titan supercomputer is made up of several banks and rows of individual units

## Nuclear energy

### Denovo

Nuclear reactor technicians need to be able to able to predict the distribution of neutrons within the reactor core in order to make sure the nuclear fuel is burning uniformly.

Titan uses Denovo to simulate the complete state of a nuclear reactor core in just 13 hours. The data from this will allow the USA to extend the life of its ageing nuclear reactors, which currently supply approximately one-fifth of the country's electricity.

## Molecular dynamics

### LAMMPS

LAMMPS stands for Large-scale Atomic/ Molecular Massively Parallel Simulator. An open-source program, it will run on an ordinary Windows PC. But it has been specifically optimised to scale well on the huge number of parallel processors in supercomputers. It uses Newton's equations of motion to model the forces between billions of atoms, molecules or larger particles at once. It's used for anything from nanotechnology to welding research.

## Climate modelling

### CAM-SE

CAM-SE models the atmosphere of the entire planet, divided into cells of 14km$^2$ (5mi$^2$)and with 26 vertical layers. It simulates the movement of wind, water vapour, carbon dioxide and ozone, including the chemical reactions that occur at different temperatures and altitudes. Titan can model more than two years of simulation time in a single day. This allows scientists to predict the effects of global warming, ozone depletion and refine long-term weather predictions.

## KEY DATES
### THE RISE OF THE SUPERCOMPUTER

**1962**
Atlas is installed at Manchester University. It was one of the first supercomputers.

**1979**
The Linpack benchmark is used to compare the speed of the most powerful supercomputers.

**1985**
The Cray-2 is built. It has more memory than every other Cray computer built to date combined.

**1996**
IBM's ASCI Red becomes the first to break the teraflops barrier and is the most reliable supercomputer ever built.

**DID YOU KNOW?** *Pangea owned by oil company Total, uses 120km (74.6mi) of fibre-optic cable to connect its processors*

## Combustion efficiency
### S3D

S3D simulates the behaviour of burning hydrocarbons very precisely. This allows fuel injection systems for diesel and biofuel engines to be fine tuned so that they produce exactly the right pattern of fuel droplets to allow them to autoignite on each stroke of the engine's pistons. Jaguar was the first supercomputer to achieve a full simulation and Titan will continue this to even greater levels of precision. This will allow engineers to design more efficient engines.

## Hard disks
### WL-LSMS

Computer hard disks and electric motors rely on magnetic materials. The WL-LSMS gets its name from the two algorithms it uses to study the interactions between the electrons and atoms in these magnets: Locally Self-consistent Multiple Scattering and the Wang-Landau algorithm, named after the physicists that developed it. By combining both algorithms, the simulation can accurately represent the behaviour of magnetic materials down to the quantum level at temperatures just above absolute zero.

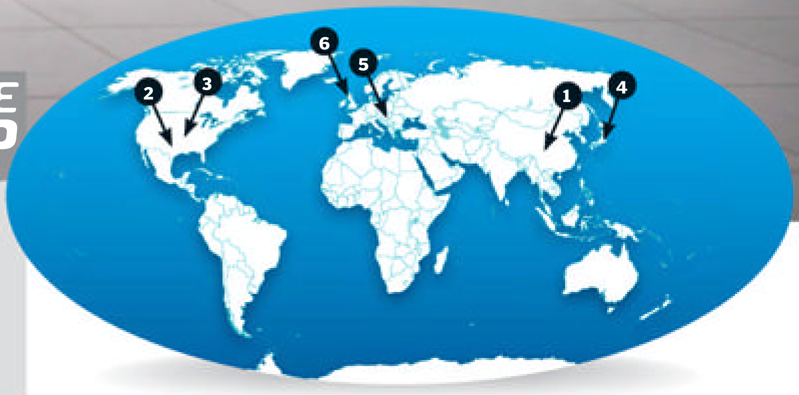
A technician working on upgrading Titan – a job that never stops

## Radiation
### NRDF

This application models the way that uncharged particles travel. The most important use for this is to simulate electromagnetic radiation in astrophysics, laser fusion and medical imaging. The NRDF application is also used as a testbed to develop new ways to program supercomputers, using algorithms that concentrate the processor power on the most important parts of the simulation and so allow it to model even larger and more complex systems.

## ON THE MAP

### Supercomputer spotting
**1** Tianhe-2
**2** Titan
**3** Sequoia
**4** K Computer
**5** Piz Daint
**6** ARCHER



© Alamy; ThinkStock; Getty; ORNL

# Trekker cameras

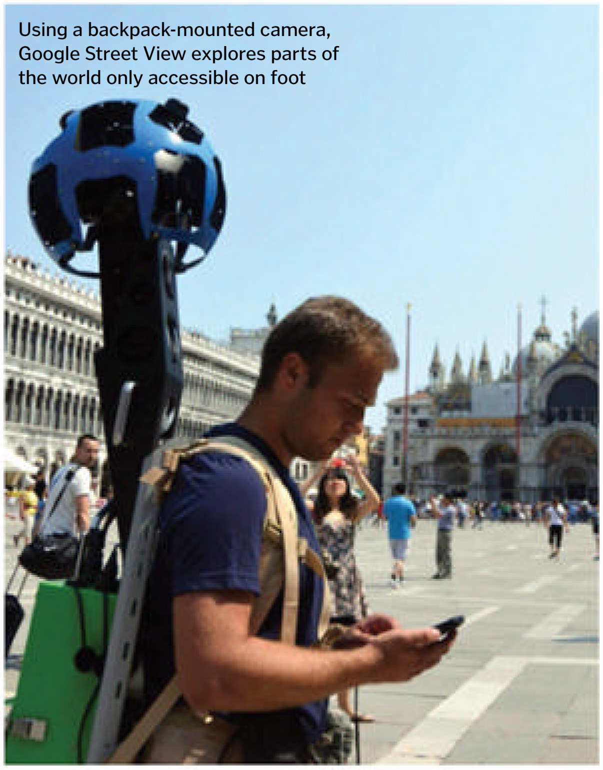
## Google Street View can now venture into city centres and the remote wilderness with its tough camera backpacks

A fleet of Google Street View cars has been capturing panoramic images of our roads and buildings for some time now, but there are certain areas they haven't been able to reach. Well, until now.

The solution lies in a 1.2-metre (four-foot)-tall, backpack-mounted camera called the Trekker. Kitted out with 15 lenses – each attached to a five-megapixel camera – it takes a photograph every 2.5 seconds, sweeping in a full panorama.

It weighs a hefty 19 kilograms (42 pounds), but volunteers seem very keen to take it into the wilderness. Charitable organisations, research institutions and the tourism industry are all eligible to apply to borrow the Trekker equipment, giving Google access to areas unreachable by their car-mounted cameras, and eventually allowing people to virtually explore national parks, ruined buildings and other difficult-to-reach areas like canyons and caves.

The equipment has already been used to map several hiking trails, including the Grand Canyon, and in the UK the complex network of canals and waterways has been recorded.


Using a backpack-mounted camera, Google Street View explores parts of the world only accessible on foot

### Making maps

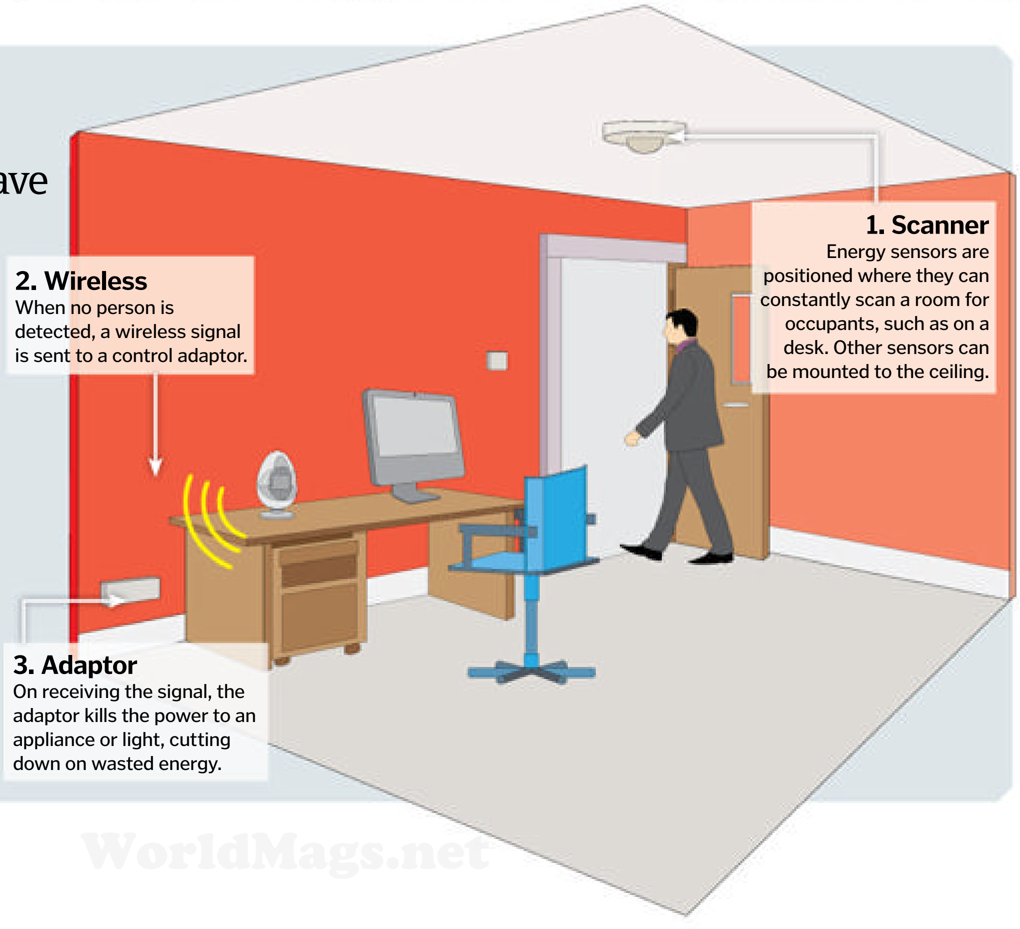
Google is extremely selective when it comes to imagery and aims to ensure that photographs are captured when the weather is clear and the view is as unobstructed as possible. Images are recorded alongside GPS information in order to ensure that their exact location is accurately mapped.

Google's camera technology uses a series of lasers to measure the distance from the lens to the subject of the image. These in turn create 3D models of the landscape that enable the best image to be selected depending on where the user is virtually positioned within Street View.

# Eco sensors

## Meet the gadgets helping to save the planet and our money

Smart energy-saving devices can detect when a room is empty using motion sensors and then turn off appliances through a control switch if no one is present. Some sensors detect body heat, while others send out waves (ultrasonic, microwave or radio) that reflect off any moving object. The former are generally preferred for energy-saving devices, as they can distinguish whether someone is standing or sitting still. When no person is detected, a signal is sent to a control box that is attached to an appliance – normally a plug socket or light switch – to turn it off. For convenience, most devices also have a time delay, so leaving the room briefly will not instantly turn off all your appliances.



**1. Scanner**
Energy sensors are positioned where they can constantly scan a room for occupants, such as on a desk. Other sensors can be mounted to the ceiling.

**2. Wireless**
When no person is detected, a wireless signal is sent to a control adaptor.

**3. Adaptor**
On receiving the signal, the adaptor kills the power to an appliance or light, cutting down on wasted energy.

© Alamy; Google

# Inside the Steam Machine

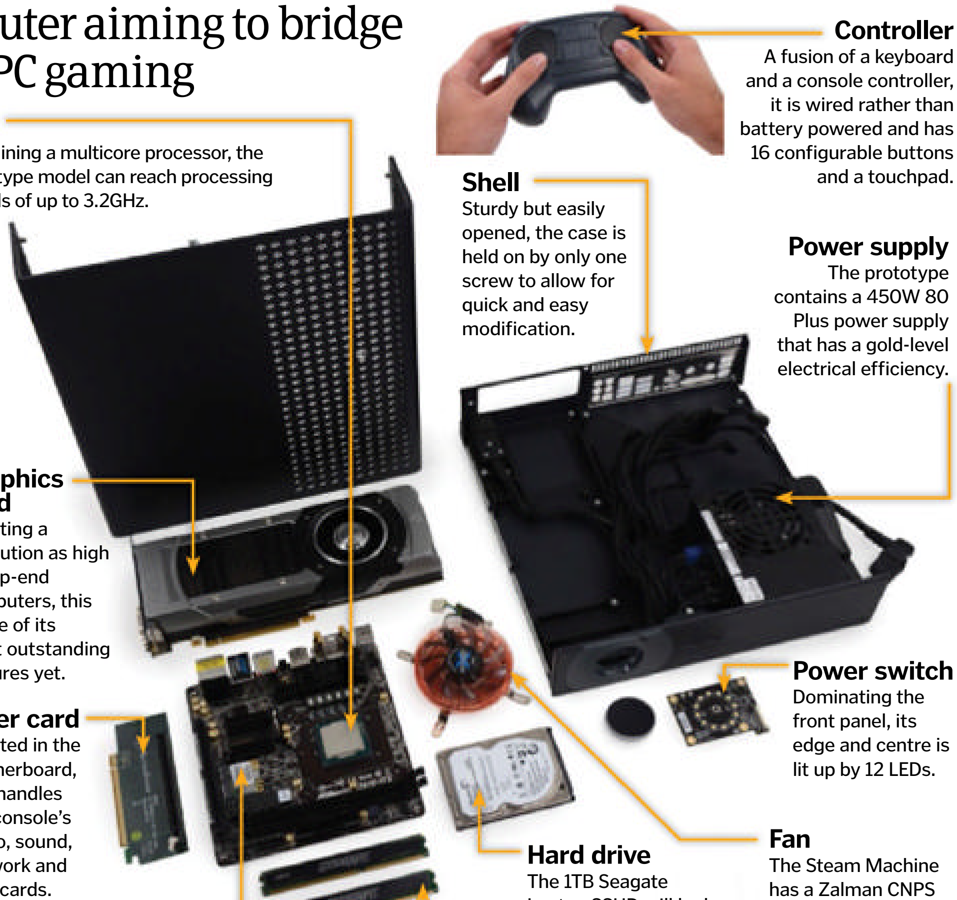
## Meet the ambitious new computer aiming to bridge the gap between console and PC gaming

The Valve Corporation is renowned for its Steam system, which distributes and manages PC, OS X and Linux gaming. Its new project, the Steam Machine, looks to revolutionise videogaming as we know it.

Designed to be a link between eighth-generation consoles and PC gaming, editing and changing the Steam Machine is actively encouraged so it can cater for your specific needs. With this in mind, unlike the Wii U, Xbox One and PlayStation 4, the console – like a PC – will have interchangeable graphics cards. Hardcore gamers can plump for the full-HD resolution Nvidia GTX Titan while more recreational users could opt for the GTX 660, which has specs equivalent to the current consoles on the market.

A controller will provide a middle ground between a console gamepad and a laptop trackpad with 16 configurable buttons and a touchscreen, aiming to simplify the PC Steam system and appeal to a broad range of gamers.

The only issue is whether games developers will up sticks and move from established formats to an unknown console, but with the stunning hardware on offer, there's no doubt many will be swayed sooner or later. 300 units are currently available to testers and the next wave of Steam Machines is scheduled for release toward the end of 2014, with models varying from as low as £300 ($500) right up to £3,570 ($6,000).



**CPU**
Containing a multicore processor, the prototype model can reach processing speeds of up to 3.2GHz.

**Graphics card**
Boasting a resolution as high as top-end computers, this is one of its most outstanding features yet.

**Riser card**
Located in the motherboard, this handles the console's video, sound, network and USB cards.

**Motherboard**
The machine's main hub, it contains a DisplayPort, DVI, USB and HDMI ports, RAM as well as a graphics card.

**Memory**
With 16GB of RAM in the CPU and 3GB in the GPU, the Steam Machine shouldn't experience any sort of lag.

**Hard drive**
The 1TB Seagate Laptop SSHD will look after all your media, from HD games to your music library and favourite films.

**Fan**
The Steam Machine has a Zalman CNPS 2X Mini-ITX for cooling, which is efficient yet quiet.

**Power switch**
Dominating the front panel, its edge and centre is lit up by 12 LEDs.

**Power supply**
The prototype contains a 450W 80 Plus power supply that has a gold-level electrical efficiency.

**Shell**
Sturdy but easily opened, the case is held on by only one screw to allow for quick and easy modification.

**Controller**
A fusion of a keyboard and a console controller, it is wired rather than battery powered and has 16 configurable buttons and a touchpad.

## Three Steam rivals

### 1 Falcon Northwest Tiki

A staggering £3,570 ($6,000) for a full-spec model with all the trimmings of 6TB storage and 16GB RAM. Adorned with glossy artwork and an Intel Core i7, this could prove to be one of the best Steam Machines.

### 2 Alienware

A subsidiary of computer giant Dell, the Alienware model will be competitively priced and similarly powered to the PS4 and Xbox One. Like all Steam Machines, however, its ultimate success will be dependent on getting the games developers to jump on board the Steam Machine bandwagon.

### 3 Bolt II

Made by Digital Storm, the Bolt II is a good all-rounder with a GTX 780 Ti graphics card and a 1TB hard drive, and it also looks the part with a sleek design. An upgrade of the original Bolt, the fans you can see are part of an advanced thermal liquid cooling system to keep it cool and quiet.

© iFixit.com; Falcon Northwest; Dell Inc; Digital Storm

# Planetariums

The incredible theatres where you can explore the night sky and beyond

You no longer need to train for several years as an astronaut to explore space, as planetariums can give you an amazing virtual tour of the universe while you keep your feet firmly on the ground. Instead of a big cinema screen at the front of the room, images are projected onto a domed ceiling to create a more immersive experience.

"There's no edge to the screen so it's like you're actually there," says Jenny Shipway, Head of the Winchester Planetarium in the UK. "During a show you shouldn't be aware of the dome at all, the dome should be invisible so your brain can imagine you are actually in this three-dimensional virtual universe."

Early planetariums simply had paintings of the night sky on the inside of the dome to give people a clear view of all the constellations. However, when projectors were developed they could depict moving celestial objects as well as fixed stars, and represent views from different points on the Earth's surface too. Traditional planetariums use mechanical star ball projectors, but they are limited to showing the stars and planets that can be seen from Earth.

The most modern planetariums now use digital projectors that are hooked up to computers instead, and can project any image onto the dome to show incredible views from anywhere in the universe. Combining data from space agencies, spacecraft and telescopes all over the world, realistic graphical representations of entire galaxies can be projected onto the dome.

"We use software called Uniview and it has a virtual model of the known universe in it", explains Shipway. "We use it as a flight simulator. It's literally like playing a computer game; just using a computer mouse you can fly anywhere. You can do a seamless zoom all the way out from Earth right to the edge of the visible universe."

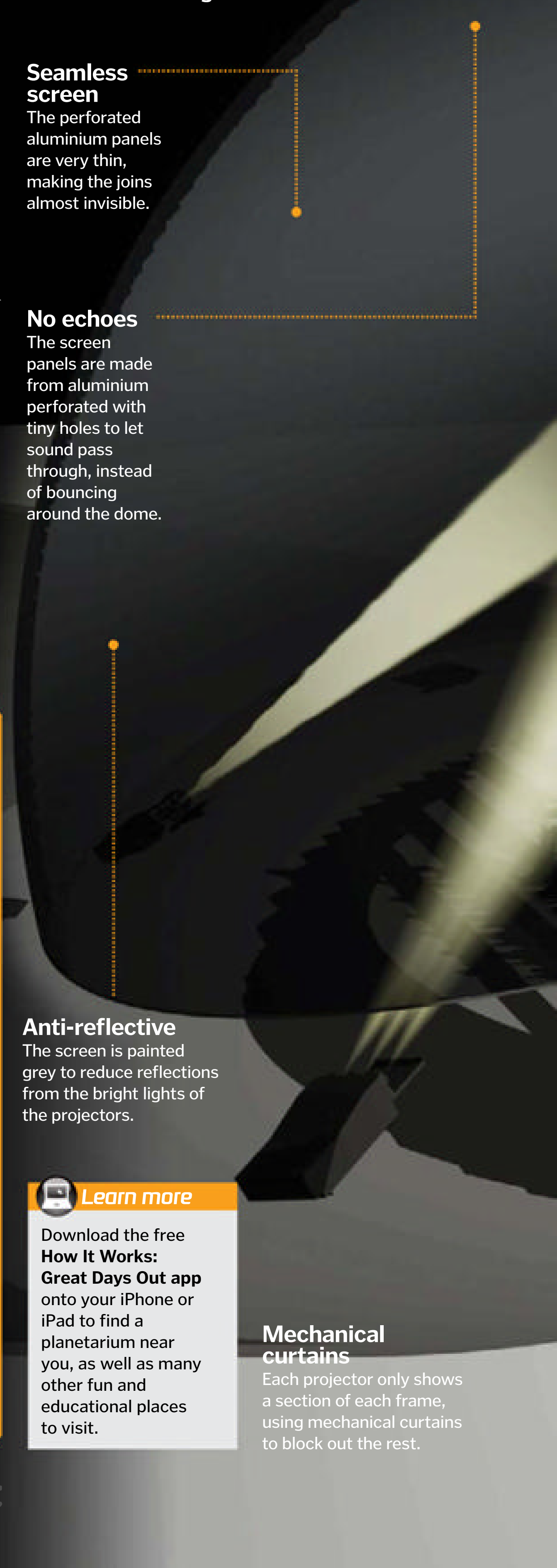
A star ball projector can only show the view from one hemisphere

## Star-ball projectors

Some planetariums still use traditional analogue projectors known as star balls. These metal spheres sit in the middle of the audience and have a bright electric lamp inside that shines light through several small lenses surrounding it. The lenses are used to represent stars, focusing light onto the planetarium dome to recreate the night sky as it can be seen from Earth. Single star balls are often fixed at one end so can only show the view from one hemisphere. However, many projectors feature two star balls attached together in a dumbbell-shaped structure so that they can represent the view from anywhere on Earth. Additional moving projectors can also be attached to show moons, planets and other moving celestial objects. The main limitation of star-ball projectors is that they can only show the view from Earth, while digital planetariums let you explore the far reaches of the universe too.

## Inside a modern planetarium

How several projectors work together to create one seamless image



**Seamless screen**
The perforated aluminium panels are very thin, making the joins almost invisible.

**No echoes**
The screen panels are made from aluminium perforated with tiny holes to let sound pass through, instead of bouncing around the dome.

**Anti-reflective**
The screen is painted grey to reduce reflections from the bright lights of the projectors.

**Mechanical curtains**
Each projector only shows a section of each frame, using mechanical curtains to block out the rest.

**Learn more**

Download the free **How It Works: Great Days Out app** onto your iPhone or iPad to find a planetarium near you, as well as many other fun and educational places to visit.

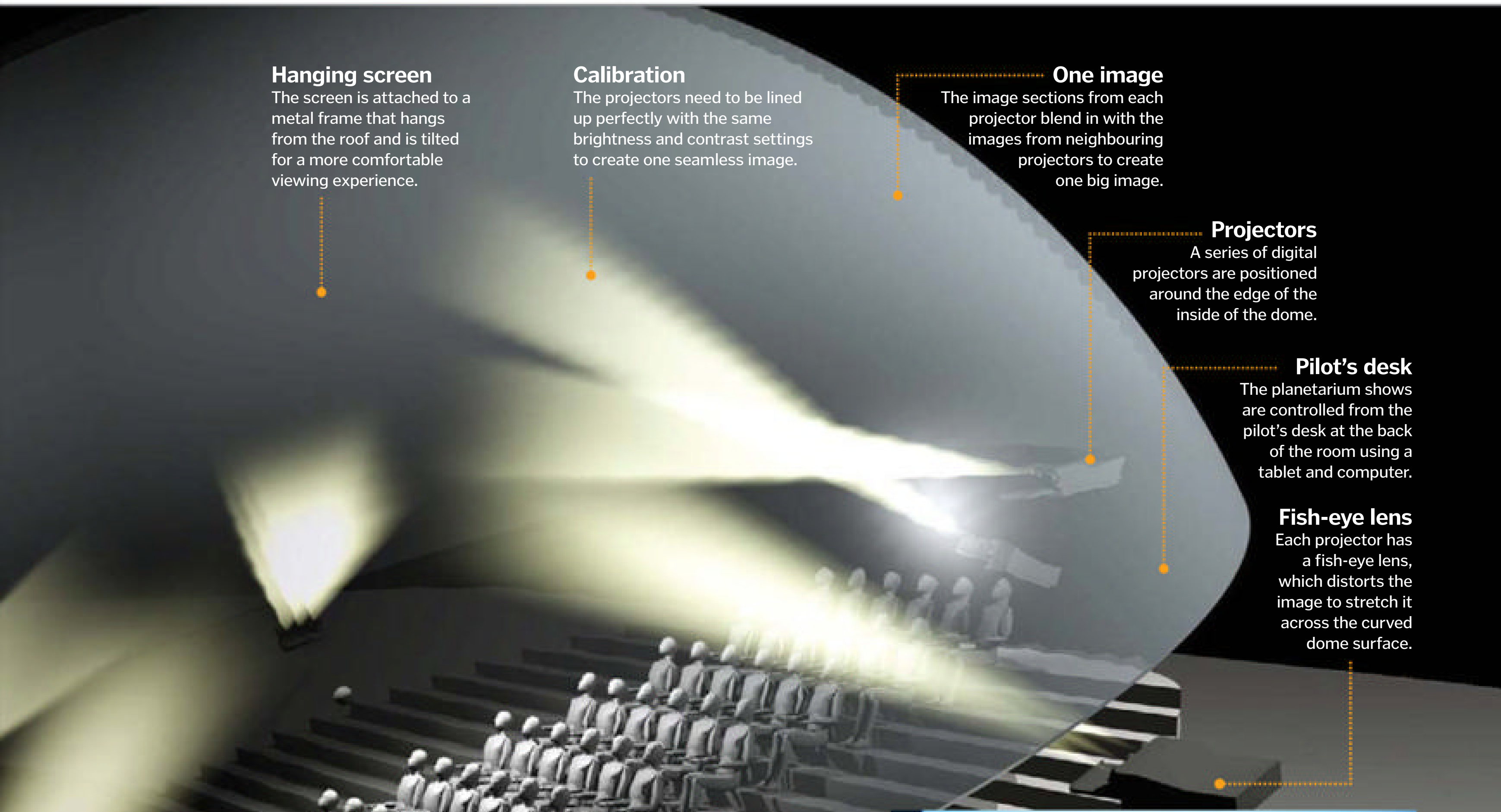
RECORD BREAKERS
ULTRA ULTRA HD

# 8K x 8K

## HIGHEST-RESOLUTION 3D PLANETARIUM

The planetarium at the Macao Science Center in Macau uses 12 projectors to display an 8,000 x 8,000-pixel 3D image. That's twice as many pixels across as ultra-HD 4K resolution!

**DID YOU KNOW?** *When a bulb is replaced in one of the digital projectors, the entire system needs to be recalibrated*



**Hanging screen**
The screen is attached to a metal frame that hangs from the roof and is tilted for a more comfortable viewing experience.

**Calibration**
The projectors need to be lined up perfectly with the same brightness and contrast settings to create one seamless image.

**One image**
The image sections from each projector blend in with the images from neighbouring projectors to create one big image.

**Projectors**
A series of digital projectors are positioned around the edge of the inside of the dome.

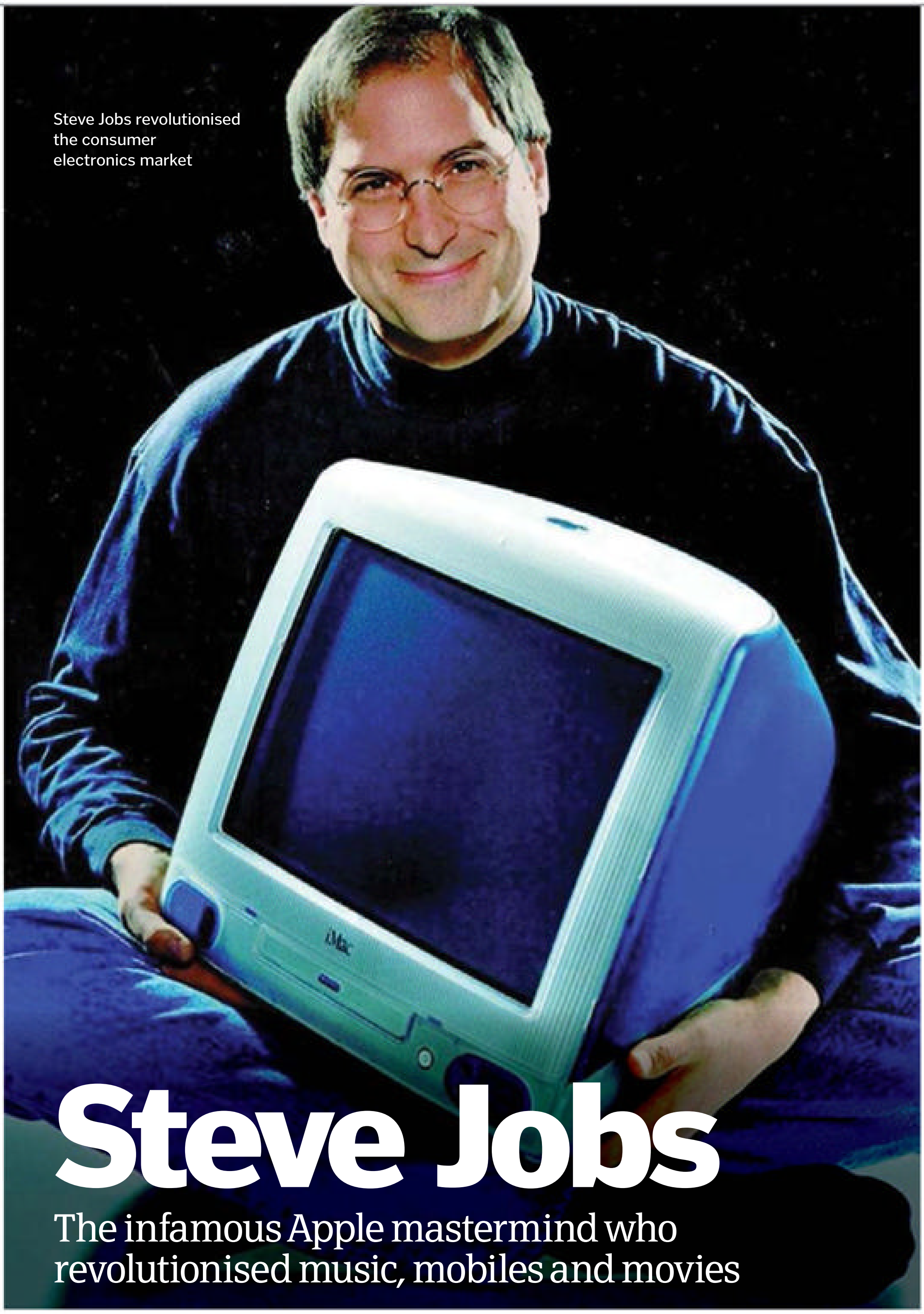
**Pilot's desk**
The planetarium shows are controlled from the pilot's desk at the back of the room using a tablet and computer.

**Fish-eye lens**
Each projector has a fish-eye lens, which distorts the image to stretch it across the curved dome surface.

Reclining seats make it much more comfortable to view the action overhead

A main server controls the footage displayed by the projectors

© Zeiss



Steve Jobs revolutionised the consumer electronics market

# Steve Jobs

The infamous Apple mastermind who revolutionised music, mobiles and movies

Steve Jobs was one of the most controversial figures of the late-20th and early-21st century. Though he was criticised for his autocratic leadership, unrelenting perfectionism and greed, his consumer insight enabled him to build one of the planet's most recognisable brands and gather a near-religious following.

Jobs was born in 1955 in San Francisco. He was adopted by Paul and Clara Jobs, a working-class couple living in Silicon Valley. While at high school, he took up a summer job at Hewlett Packard where his passion for technology grew. It was during this time that he met Steve Wozniak, and on graduating the pair began building a computer in his parents' garage. With Wozniak's technical genius and Jobs' innovation, they were able to build a new type of personal computer. The Apple I, which went on sale in 1976, came complete and worked straight out of the box. In the dawn of the personal computing boom, it was an instant success, and sales of the second model skyrocketed. Apple Computer, Inc was born.

But Jobs' prosperity at Apple was short-lived. The Macintosh model failed to take off and three of the six Apple factories were shut down. Jobs' autocratic style of leadership also led to an internal power struggle, and in 1985 he left Apple. Instead, Jobs founded a company called NeXT that built workstations for the higher-education market. He also bought Graphics Group, which made high-end hardware for computer-animated films. Jobs transformed it into a studio, renamed it Pixar, and turned it into one of the biggest names in the film industry.

Meanwhile, Apple was teetering on the brink of bankruptcy. The launch of the much more

> "With the Mac battling for survival in a Windows world, Jobs decided on a different direction"

## The life of Jobs

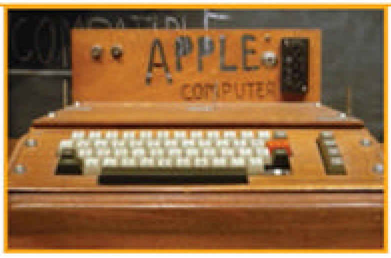
**Steve Jobs' path from birth to success wasn't straight and easy**

**1955**
Jobs is born to two unmarried students, and adopted by Paul and Clara Jobs.

**1972**
Jobs takes a job as a technician at Atari, a successful videogame and home computer company.

**1974**
Travels to India, where he converts to Buddhism, becomes a vegetarian and experiments with psychedelic drugs.

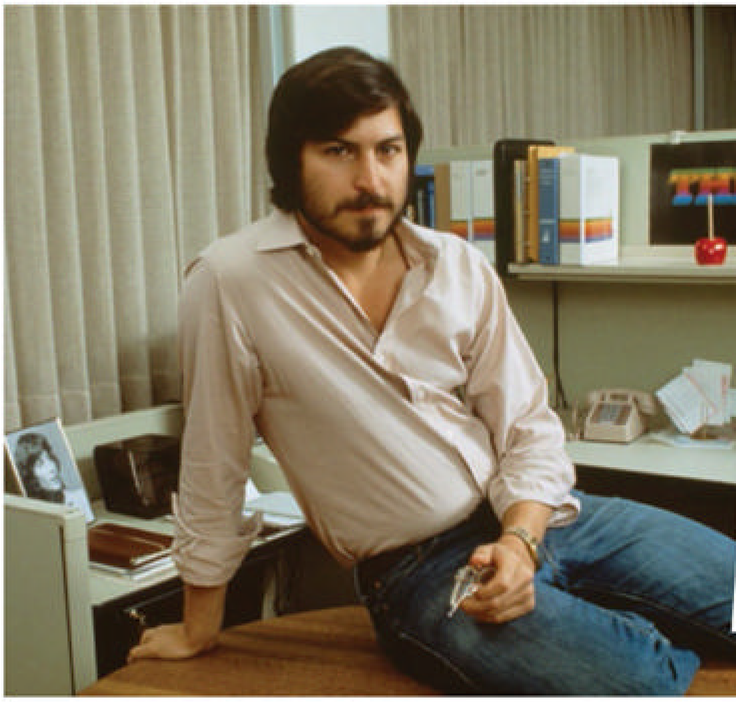
**1976**
Together with his friend Steve Wozniak, he builds the very first Apple I computer in his parents' garage.



## The big idea

### Why was the iPod so successful?

In 2000, Apple was surviving but not thriving. The release of the iPod in 2001 changed all this. But what made it stand out from all the other MP3 players on the market? First, the iPod was incredibly easy to use. With only five buttons, a click wheel and a simple menu, it was easy to operate and navigate, as well as arguably being the most stylish player on the market. It also did a really good job of integrating the player, the computer and the software, and was Windows-compatible as well. Along with the launch of iTunes, these all equated to an unparalleled success story.



affordable Windows 95 meant the mouse and graphical user interface were now industry standards, and Apple's turnover plummeted. Despite this, in 1996 Apple paid more than $400 million for NeXT and Jobs returned to Apple.

With the Mac battling for survival in a Windows world, Jobs decided it was time to take a different direction. In 2001, he unveiled the iPod – a sleek, statement device that met the demand for music on the move and was to become the best-selling portable music player of all time. This was followed by the launch of the iTunes music store in 2003. In 2007, thousands of devoted Applites (the nickname for devoted Apple fans) queued for blocks to get their hands on Jobs' latest brainchild: the iPhone. By 2010, Apple had sold almost 90 million of them.

In October 2011 Jobs died from complications of pancreatic cancer, leaving Apple the second-most valuable company in the world with £50 billion ($80 billion) in the bank. His mark had been well and truly engraved into the company, and remains on the property of millions of people around the world.

**ABOVE LEFT** A young Steve Jobs in his office at Apple

**ABOVE RIGHT** Jobs (left) with Sculley and Wozniak in 1984

## Top 5 facts: Steve Jobs

### 1 Fruit influence

Jobs was on a fruitarian diet when he christened Apple. He had just come back from an apple farm and thought the name sounded "fun, spirited and not intimidating."

### 2 Buddhist beliefs?

He converted to Buddhism after an inspiring trip to India, but was consistently criticised throughout his career for his reluctance to produce environmentally sustainable products.

### 3 Inner artist

Jobs briefly attended art school, but dropped out after only one term. However, he did put the skills he learned there to use while creating Apple's sleek, well-designed products and gadgets.

### 4 Control freak

As a perfectionist, Jobs insisted on a 'closed system of control', which meant he had control over each and every aspect of a product from start to finish.

### 5 Film credits

Jobs bought Graphics Group for $5 million in 1986, renamed it Pixar and changed it into an animation studio. He was later credited as an executive producer on the studio's first full-length film, 1995's *Toy Story*.

**1977**
The Apple II is a roaring success. Apple Computer, Inc is born.

**1985/6**
Jobs leaves Apple, founds NeXT and forms Pixar out of a computer-hardware firm.

**1996**
Returns to Apple as an advisor and steers it away from bankruptcy.

**2001**
The iPod is launched and becomes the most successful portable music player of all time.

**2007**
Jobs introduces the iPhone. Shops report shortages within an hour of it going on sale.

**2011**
Jobs dies of pancreatic cancer, aged 56.

© Rex Features; Corbis; Apple Inc

# The Skype Translator

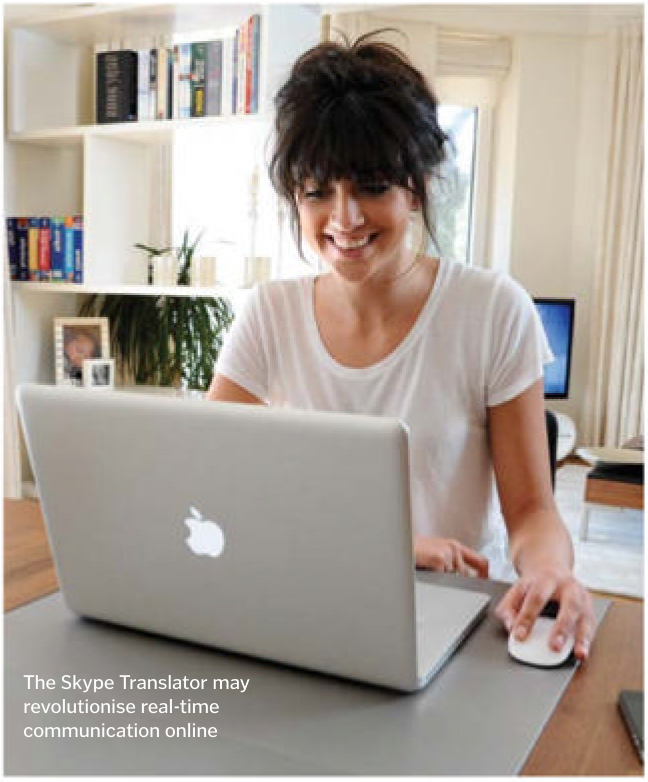
## The beginning of the end for language classes?

The immensely popular internet phone and messaging service Skype has approximately 300 million monthly global users. For its next trick, the Microsoft-owned service plans to break down language barriers by automatically translating multilingual voice calls. This bold claim is backed up by some impressive technology.

Using a combination of existing speech recognition, text-to-speech and machine-translation technology, the program will translate any word you utter into a text format of the desired language. Current translation programs use a similar system but can currently only work if they are in the same room. The new Skype software will look to change that, allowing for fully translated international calls.

One stumbling block is the vast amount of different dialects and accents used all over the globe. Because of this, some say there will always be a need for human interpreters as computers can never be completely accurate to detect the really subtle language variations.

The translator is scheduled to be released for the public on Windows 8 by the end of the year, though you can sign up for the Preview version. Other companies such as Lexifone, Google and NTT DoCoMo are working on a similar system. Skype Translator is intended to help in all areas from education to business to international relations. Or maybe just to help you and your German exchange buddy communicate better.


The Skype Translator may revolutionise real-time communication online

# How targeted advertising works

## How is the internet uncannily accurate at knowing what kind of things we like?

Advertisers use a range of information about you, like your age, gender and location, to flag up relevant ads

If you look at a product on the web you may find that it follows you around, popping up in adverts on seemingly unrelated websites. This is one of the simplest forms of targeted advertising. When you visit a website, third-party advertisers leave tracking cookies in your browser, enabling them to monitor your online activity and remind you later of items or services you looked at earlier.

Search engines like Google collect data about the searches performed from a particular IP address, taking into account search terms, but also the user's location. They even target advertising based on keywords collected from the messages in your email inbox. Your activity on Google-owned sites like YouTube is also fed back to advertisers for use in targeting.

Social networks sell data to advertisers too. Facebook uses the personal information that you provide about your life and interests, along with your 'Likes' and friendships, to help advertisers pitch to a suitable audience.

# The computer mouse

## How did one little invention help us point and click?

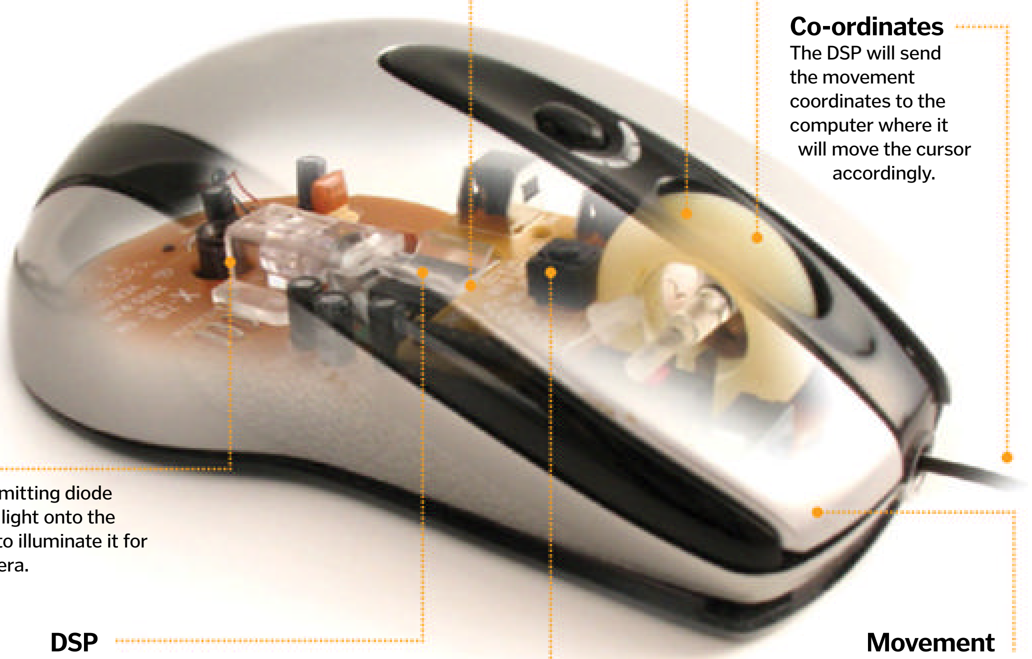
Chances are if you are using a mouse to navigate around your computer that it's an optical mouse. It was invented in 1980 and has pretty much completely replaced the ball-guided mouse. An optical mouse works using microscopic imaging technology. First, a tiny camera inside the mouse photographs your desk or mousemat. The red glow you can see if you turn it upside down is a red light-emitting diode (LED) inside that projects light onto the surface. When the light hits the surface and bounces back into the mouse it hits a complementary metal-oxide semiconductor (CMOS). This sends a message to a digital signal processor (DSP), which closely analyses changes in the pattern of the surface. Once it registers a movement, it sends a signal to the computer, which translates that information into a cursor movement. These adjustments happen hundreds of times every second, so it follows your hand movements in extreme detail.

On top of the mouse is usually either a wheel or a tiny rubber ball. These use the same technology as early ball-guided mice. Rotating the wheel or ball with your finger moves a couple of rollers. These are wired up to a processor which analyses how much each roller has moved and allows you to move a web page or document up and down or, with the ball-topped mouse, side to side.

These developments have greatly helped day-to-day computing, making navigating around the screen much easier than before and revolutionising PC gaming by enabling millimetre-perfect movement.

## Inside an optical mouse

**What goes on inside your mouse to help you work, rest and play?**



**Camera**
A tiny camera sits in the middle of the mouse, pointing downward and taking 1,500 pictures of the surface below every second.

**Wheel**
Many mice also feature a wheel on top for additional ease of navigation.

**Up and down**
This provides vertical movement, meaning you can scroll up and down a web page or document.

**Co-ordinates**
The DSP will send the movement coordinates to the computer where it will move the cursor accordingly.

**LED**
A light-emitting diode shines a light onto the surface to illuminate it for the camera.

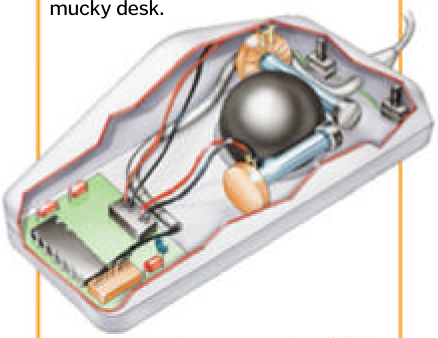
**DSP**
The digital signal processor looks at the images and notices if there have been any changes in the surface below the mouse.

**CMOS sensor**
A complementary metal-oxide semiconductor receives the light that has bounced off the surface and sends it for processing.

**Movement**
If there are any changes in the pattern below the mouse, the sensors will pick that up and work out how much it has moved.

## How the roller-ball mouse worked

The roller-ball mouse was the standard design for years before the optical mouse came along, but what went on inside that casing? As you moved your hand around, the ball rolls too. The ball touched two rollers, one behind and one to the side of the ball to detect vertical and horizontal motion respectively. Wires attached the rollers to a circuit board, transmitting movement data. This data was used to move the cursor around the screen with a greater degree of accuracy than the earlier wheeled mouse. The main downside of the roller ball mouse wasn't anything to do with the electronics. Dirt and grime from the surface it was on would collect inside the hole the ball emerged from, making it stick. The new optical mouse does provide a greater degree of accuracy, but its main advantage over the roller ball is that it won't stick if you have a mucky desk.



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# How does virtual reality work?

It's been under development for decades, but new technology in the VR field is making CG environments more real than ever

With the 3D craze continuing at your local cinema, what if you could actually immerse yourself in a completely realistic environment and not just have Iron Man flying out the screen towards you? How about going on holiday without leaving your armchair, playing dangerous sports with no risk of injury or taking your videogames to an entirely new level? This has been the promise of virtual reality (VR) since its inception back in the Fifties – and it's starting to be realised with new domestic technology that is within reach of everyone.

Virtual reality isn't like 3D which merely gives the *appearance* of depth on a flat screen; it actually places you within a 360-degree environment that your senses tell you is real.

Remember, what your eyes see or your fingers touch is just electrical impulses interpreted by your brain. VR essentially works by tricking your senses into believing that they are experiencing a real environment when, in fact, it is completely computer generated.

Early virtual world creation applications used VRML (Virtual Reality Modelling Language). This has been superseded by X3D, which uses an XML-based file format. This modelling language can be used with 3D graphics applications, including Blender, which offers a host of 3D rending features for incorporation into VR environments. There are many ways to create VR worlds that can be viewed in a browser, but it's games which have seen the technical advances have been made.

Outside of gaming, virtual reality has many other applications though. The US Army has adopted what it calls its Close Combat Tactical Trainer (CCTT), which uses VR to train soldiers by creating fighting avatars. The system is rather like a cross between the videogame *Call Of Duty* and *Star Trek*'s holodeck.

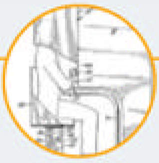
It's the immersive nature of virtual reality that differentiates it from augmented reality or 3D. Also used by NASA and for advanced surgical training, VR is about to have a renaissance thanks to systems like the Sony HMZ-T2 that offers OLED HD screens, the Sensics zSight and, of course, the Oculus Rift (which we tear down later in this feature).

For VR to work convincingly, you have to feel that you are completely immersed in an

## KEY DATES

### HISTORY OF VR

**1962**
Sensorama is one of the earliest fully immersive analogue technologies to offer 3D stereoscopic images.

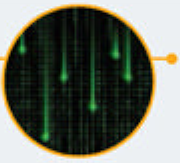


**1968**
Bob Sproull and Ivan Sutherland use cathode ray tubes in the first head-mounted display.

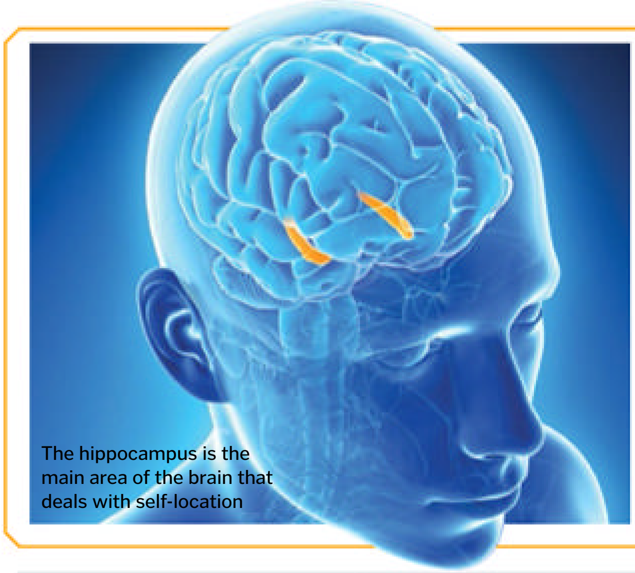
**1986**
Thomas Furness develops the 'Super Cockpit' program for the US Air Force.

**1987**
Computer scientist Jaron Lanier – a pioneer of early VR tech – coins the term 'virtual reality'.

**1999**
*The Matrix* is released, and popularises the idea of entering a super-realistic CG environment.



**DID YOU KNOW?** *A full-body immersion suit for gaming called the PrioVR is currently seeking funding on Kickstarter*



The hippocampus is the main area of the brain that deals with self-location

## Tricking the brain

VR works as the brain uses systems including proprioception (the sense of where limbs are in space) and how the eyes orientate to the scene when the head moves. Also, place cells in the hippocampus have been shown to be the centre for self-location, which is used by the brain when assessing where the body is in space.

Ultimately, the brain has to believe the concept of presence, which is based on the brain's past experience of what it feels like to walk down a street, for instance, and how this compares to the virtual street portrayed in the VR environment.

The brain compares these past experiences with the CG environment and decides how real it actually is. Also, when virtual limbs are created in the virtual world, the brain is surprisingly willing to merge the fake with the real. Indeed, in one test VR users pulled their arms away from a virtual fire.

## Virtual nausea

Latency is the single biggest barrier to building realistic virtual environments. If the images seen through the HMD are not redrawn (ie rendered) quickly enough, the illusion of reality is shattered. Oculus Rift gets around this issue with what the developers call 'predictive tracking'.

This technology guesses where the user might look next and gets a head-start on rendering the environment. Latency must be minimised at below 50 milliseconds if the brain isn't to detect any lag in the images.

Early VR systems caused motion sickness in some users. This can't be completely cured in some people, but VR systems today have hardware and software that work together to minimise large changes in focus depth or vergence (how eyes focus on an object), which can cause nausea.

Recent developments may combat the motion sickness experienced by some users

environment, but also have the ability to interact with it. It's the interaction – known as telepresence – that sets VR apart from other virtual world systems and 3D cinema. Also, for VR environments to be perceived as real, feedback has to be present.

Think about how you interact with the real world. You can touch and pick up objects, feel their texture and influence things when you open a door or pick up your remote. This is often referred to as force feedback. If you're a gamer, vibrating controllers and body armour that enables you to feel a bullet hit are good examples of force feedback that are collectively called haptic systems. These are essential components of building a realistic VR environment that will fool your brain.

VR systems are often controlled with gaming pads in more advanced systems using VR gloves. Early attempts included Nintendo's Power Glove, with VR systems today favouring a controller approach using platforms such as the Razer Hydra system that is being used extensively with the Oculus Rift head-mounted display (HMD). The Razer Hydra works by using a base station which emits a weak magnetic field. It uses its amplification circuitry, digital signal processor and positioning algorithm to translate the data collected from the controllers into positional and orientation information that in turn is used to control elements of the CG environment which the user is in.

VR uses a number of technologies together to deliver a convincing world to the explorer. The

## Key VR hardware

### 1 Head-mounted display

The most important component of a VR setup. Today's HMDs work via hi-res screen technology. As the eyes are our primary sense, HMDs have to display photorealistic images. The HMD is also packed with motion-tracking devices like accelerometers to place the user in a VR world.

### 2 Controller

Joysticks, gamepads and gestures are all used to control VR environments. Systems like the Razer Hydra even let you interact with your environment. They work like a remote control to pick up objects and move you around.

### 3 Body suit

For the ultimate in VR experiences, full body suits have been designed. These contain a number of sensors that detect motion and translate this into the movement of an avatar. Suits can also include hot, cold and vibration points that the computer can adjust.

### 4 Gloves

Paired with an HMD, VR gloves work by attaching sensors to the fingers. Each sensor detects the movement of each finger and translates this into an action within the world. Reach out with a VR hand and you can pick up an object in the CG environment.

### 5 Treadmill

A new generation of treadmills designed for VR is emerging. Using special shoes that interact with the treadmill belt you get a much more realistic sense of walking and jumping etc.

HMD is the most important, and uses a technique called stereoscopy that feeds slightly different images to each eye. The Oculus Rift uses a single LCD screen with a colour depth of 24 bits per pixel and includes a 1,000-Hertz adjacent reality tracker that reduces latency to improve the overall quality of the images as the HMD moves. Lenses in front of each eye give the appearance of depth and mean the images totally encompass the wearer's field of vision. With head-mounted displays including tracking software, as the user moves their head, the virtual world moves with them.

A built-in three-axis gyroscope, magnetometers (which measure the strength of the Earth's magnetic field) and accelerometers (to measure how fast the HMD is moving in space) all allow accurate head tracking and therefore the perception that the environment is real. These three technologies change the images fed to the HMD as the wearer moves around. This sense that the scene they see moves as they do is how VR tricks your brain into thinking you are in a real place.

Movement is also a key component of convincing VR. The Omni from Virtuix is the perfect companion for a VR HMD and controller. The treadmill works with the user wearing bespoke pinned shoes. When the shoes make contact with the grooved, low-friction surface of the Omni, the plates within the treadmill move to mimic the walking on a flat surface. Users can even run or jump with their relative position fed back to the computer generating the images shown on the HMD. As users walk unsupported – just as you would in the real world – the illusion of movement through the VR space is assured.

Of course, a computer-generated environment is just that, so how does a VR system ensure you suspend your disbelief and react to the VR world as if it were real? A convincing VR environment must have graphics of a high enough resolution with images fed to the HMD at around 30 frames per second for it to be believable. A precise combination of texture, shading and lighting effects are all needed to generate a lifelike world. Also, sound should be directional and immerse the user in order to make the audio experience equally as convincing.

VR tech has numerous potential applications, notably in combat training

With hi-res images, haptic systems and surround sound, stand on the edge of a virtual cliff and you will feel your heart rate rise – not recommended for anyone with vertigo!

A recent addition to the market was Apple's newest Mac Pro with Intel Xeon E5 Ivy Bridge processors, which has 12 cores. Intel is claiming that this latest generation of chips doubles the CPU performance of its current Xeon range. And with dual AMD FirePro workstation GPUs that can run up to three 4K displays simultaneously, the new Mac Pro is the perfect reality engine for VR exploration.

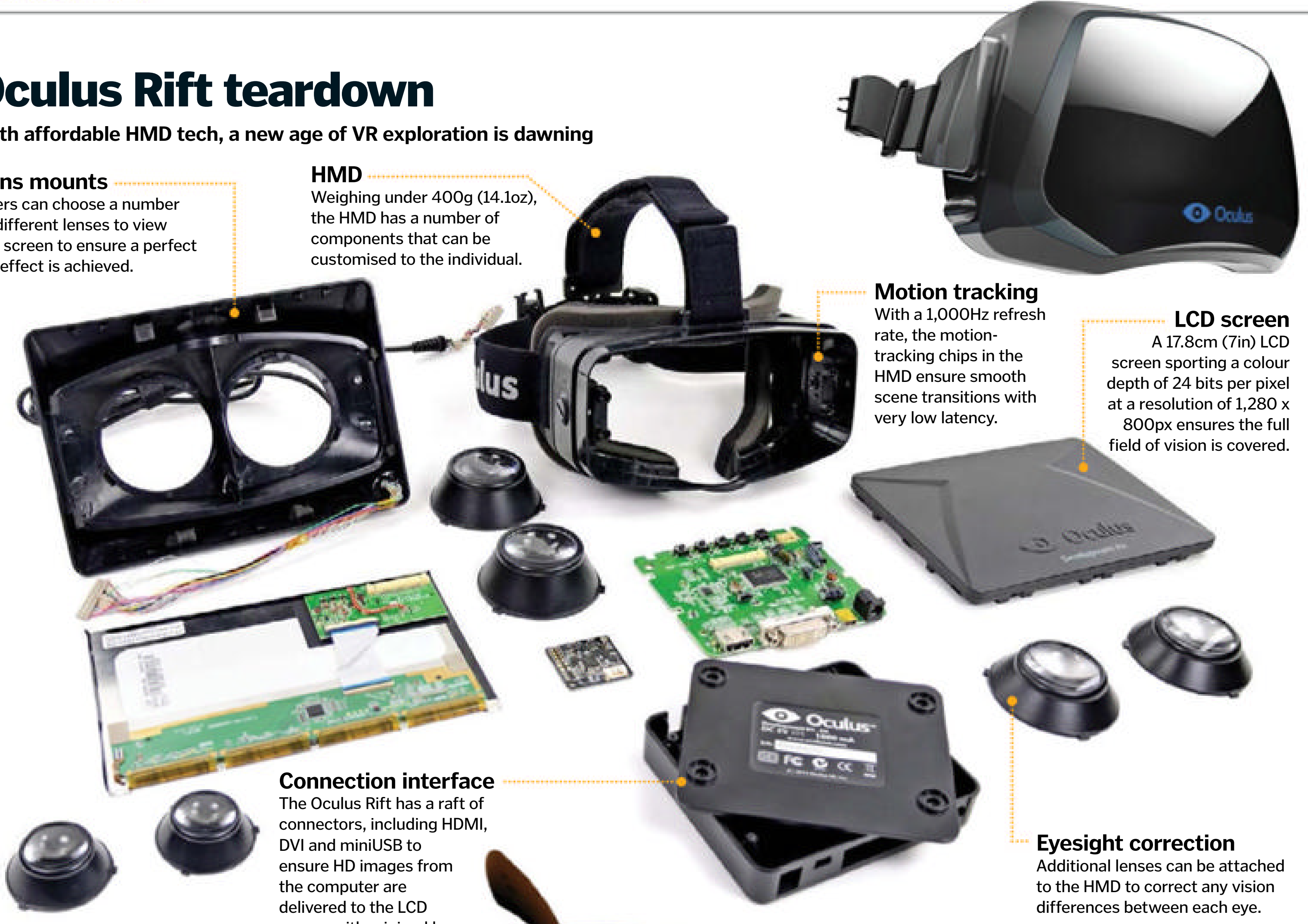
The Oculus Rift is the latest HMD to attempt to place VR into the hands of everyone, as in the past the prohibitive cost of VR systems meant that only the likes of NASA and the military had deep enough pockets. What Oculus Rift and the rumoured VR HMD for PlayStation 4 could herald is a new age of interactive and immersive experiences. Gaming is clearly the most obvious application, but how about VR on mobile devices? If you have a favourite iPad app, you could add an Oculus Rift HMD for a whole new immersive experience.

If you have often thought that *Star Trek*'s holodeck would offer the ultimate in virtual living, the VR technology that is coming soon could very well offer a taste of what a holodeck might feel like in your very own home.

**DID YOU KNOW?** *Getting ill in space is no joke, which is why NASA uses VR to test potential astronauts for motion sickness*

# Oculus Rift teardown

**With affordable HMD tech, a new age of VR exploration is dawning**



**Lens mounts**
Users can choose a number of different lenses to view the screen to ensure a perfect 3D effect is achieved.

**HMD**
Weighing under 400g (14.1oz), the HMD has a number of components that can be customised to the individual.

**Motion tracking**
With a 1,000Hz refresh rate, the motion-tracking chips in the HMD ensure smooth scene transitions with very low latency.

**LCD screen**
A 17.8cm (7in) LCD screen sporting a colour depth of 24 bits per pixel at a resolution of 1,280 x 800px ensures the full field of vision is covered.

**Connection interface**
The Oculus Rift has a raft of connectors, including HDMI, DVI and miniUSB to ensure HD images from the computer are delivered to the LCD screen with minimal lag.

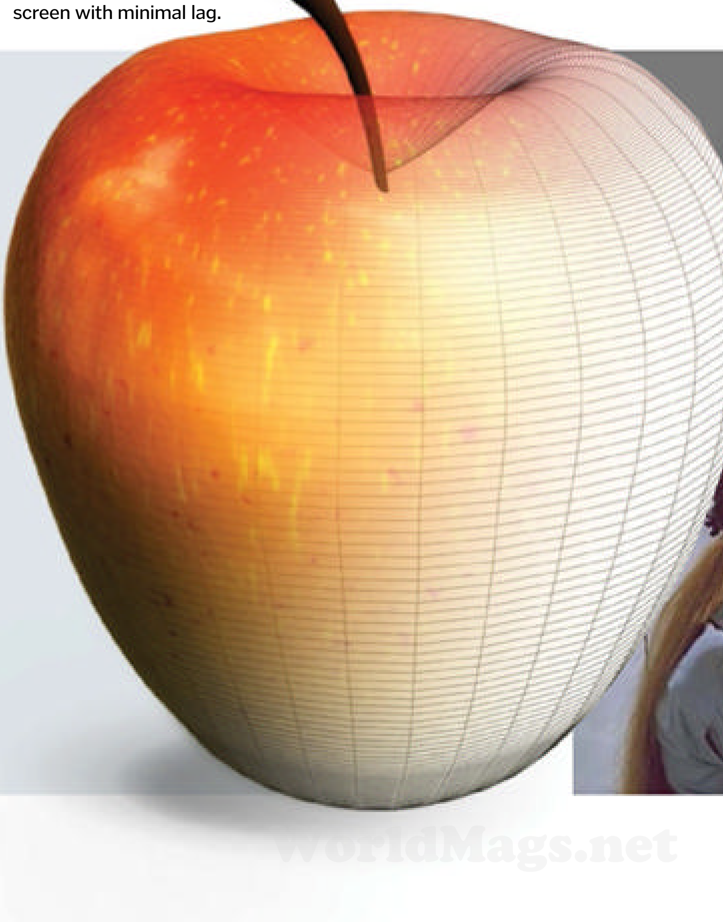
**Eyesight correction**
Additional lenses can be attached to the HMD to correct any vision differences between each eye.

## Designing virtual worlds

There is a plethora of software that can build virtual worlds from commercial offerings, from LightWave, Bryce and modo to open-source applications like Art of Illusion and Blender that can make photorealistic environments, avatars and indeed anything else a virtual world needs.

All these applications use a wireframe, onto which polygons are grafted to create the images needed for a VR environment. 3D graphics applications use colour, reflectance, perspective and texture to render each component of the VR scene.

These applications attempt to duplicate the world around us. This isn't easy, as we know what an apple looks and feels, or how water glistens in sunlight, etc. The skill of the graphics artist and power of the graphics processing of the computers they are using is how VR spaces can seem so real.



All VR models start off as wireframes

The Virtual Environment Workstation was an early VR system developed in the Eighties by NASA

© Alamy; Thinkstock; iFixit.com; NASA; Oculus VR

# ENGINEERING

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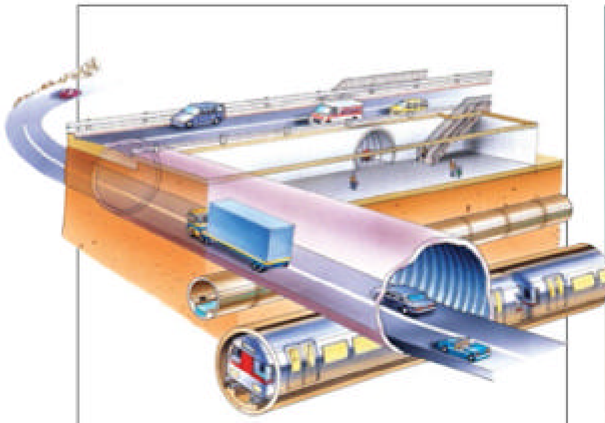
Find out how to go about destroying large buildings



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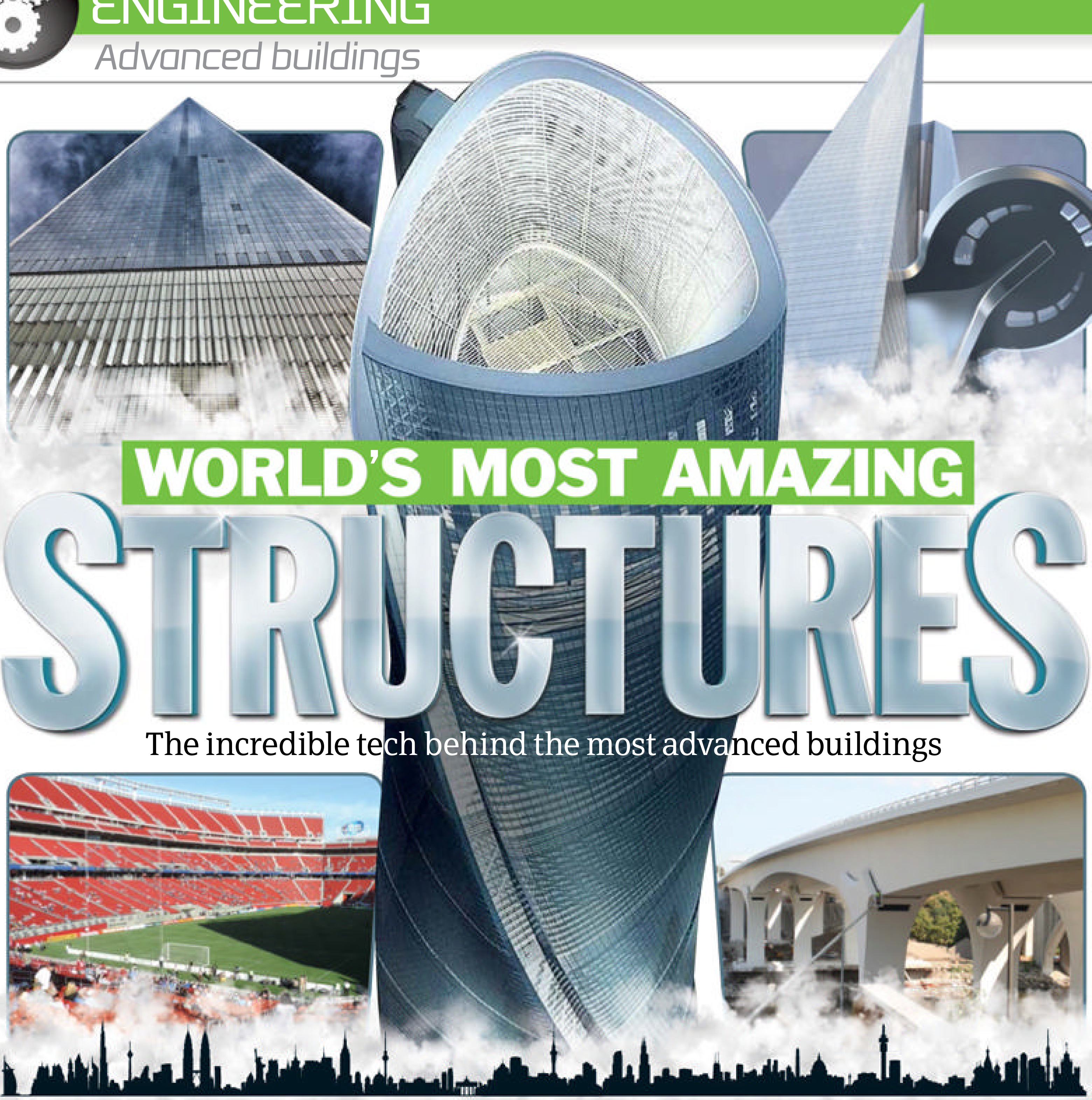


# WORLD'S MOST AMAZING STRUCTURES

The incredible tech behind the most advanced buildings

Ever since the pyramids of the Egyptians or the temples of the Greeks, humans have been racing to build bigger, better and smarter structures. However, with greater height comes greater responsibility, so the race for the skies has meant more advanced technology is required to keep the world's skyscrapers safe from winds and earthquakes.

This has led to a surge of structures modelled on a computer before a single brick or pane of glass is put in place. The technology available to designers and architects changed the design of the Sydney Opera House and showed that rotating Burj Khalifa – the world's tallest building – by 120 degrees would reduce stress from high winds. New structures are also being loaded with technology to enhance the user experience, make them more eco-friendly or relay structural information to the authorities.

From bridges to sports stadiums, technology plays an increasingly important part in building planning. The modern need for Wi-Fi connectivity and smartphone-controlled devices in the home and office has increased the challenge for architects. It is getting increasingly difficult to continue breaking the record for the world's tallest building, so the development of green technology, solar panels and other smart technology is becoming a key battleground for companies trying to design headline-grabbing structures. A mixture of necessity and posturing has accelerated the development of smart buildings, so let us take you through some of the coolest structures in the world today. ▶

## HEAD 2 HEAD
BUILDING FAILS

**1. DANGEROUS**

### Leaning Tower of Pisa

Soft ground and poor foundations caused the Italian bell tower to lean during construction. Work was halted for nearly 100 years.

**2. MORE DANGEROUS**

### Palau de les Arts Reina Sofia

Valencia's opera house looks visually stunning but has fallen into ruin with ceramic tiles falling on the heads of passers-by.

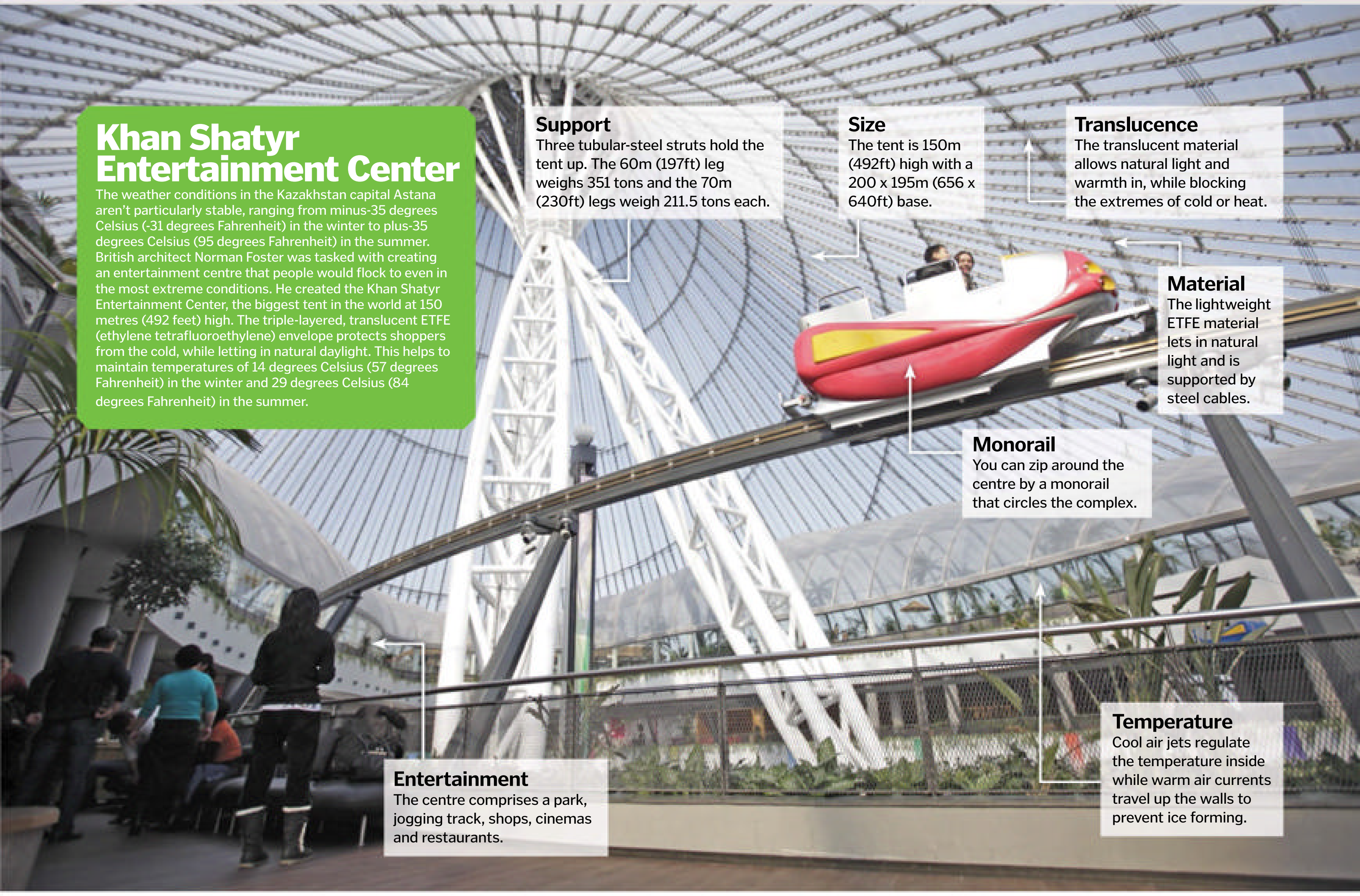
**3. MOST DANGEROUS**

### 20 Fenchurch Street

Nicknamed the Walkie-Talkie, this London building's concave design focuses the Sun's rays with such intensity it can melt cars.

## Khan Shatyr Entertainment Center

The weather conditions in the Kazakhstan capital Astana aren't particularly stable, ranging from minus-35 degrees Celsius (-31 degrees Fahrenheit) in the winter to plus-35 degrees Celsius (95 degrees Fahrenheit) in the summer. British architect Norman Foster was tasked with creating an entertainment centre that people would flock to even in the most extreme conditions. He created the Khan Shatyr Entertainment Center, the biggest tent in the world at 150 metres (492 feet) high. The triple-layered, translucent ETFE (ethylene tetrafluoroethylene) envelope protects shoppers from the cold, while letting in natural daylight. This helps to maintain temperatures of 14 degrees Celsius (57 degrees Fahrenheit) in the winter and 29 degrees Celsius (84 degrees Fahrenheit) in the summer.



**Support**
Three tubular-steel struts hold the tent up. The 60m (197ft) leg weighs 351 tons and the 70m (230ft) legs weigh 211.5 tons each.

**Size**
The tent is 150m (492ft) high with a 200 x 195m (656 x 640ft) base.

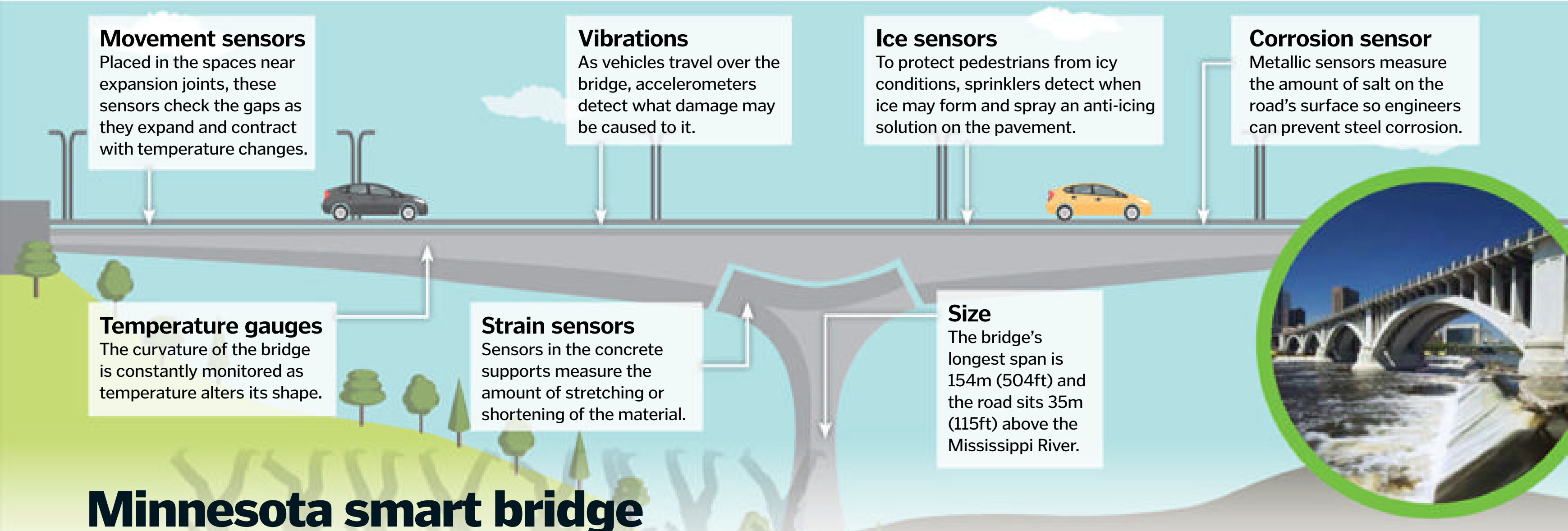
**Translucence**
The translucent material allows natural light and warmth in, while blocking the extremes of cold or heat.

**Material**
The lightweight ETFE material lets in natural light and is supported by steel cables.

**Monorail**
You can zip around the centre by a monorail that circles the complex.

**Entertainment**
The centre comprises a park, jogging track, shops, cinemas and restaurants.

**Temperature**
Cool air jets regulate the temperature inside while warm air currents travel up the walls to prevent ice forming.



**Movement sensors**
Placed in the spaces near expansion joints, these sensors check the gaps as they expand and contract with temperature changes.

**Vibrations**
As vehicles travel over the bridge, accelerometers detect what damage may be caused to it.

**Ice sensors**
To protect pedestrians from icy conditions, sprinklers detect when ice may form and spray an anti-icing solution on the pavement.

**Corrosion sensor**
Metallic sensors measure the amount of salt on the road's surface so engineers can prevent steel corrosion.

**Temperature gauges**
The curvature of the bridge is constantly monitored as temperature alters its shape.

**Strain sensors**
Sensors in the concrete supports measure the amount of stretching or shortening of the material.

**Size**
The bridge's longest span is 154m (504ft) and the road sits 35m (115ft) above the Mississippi River.

## Minnesota smart bridge

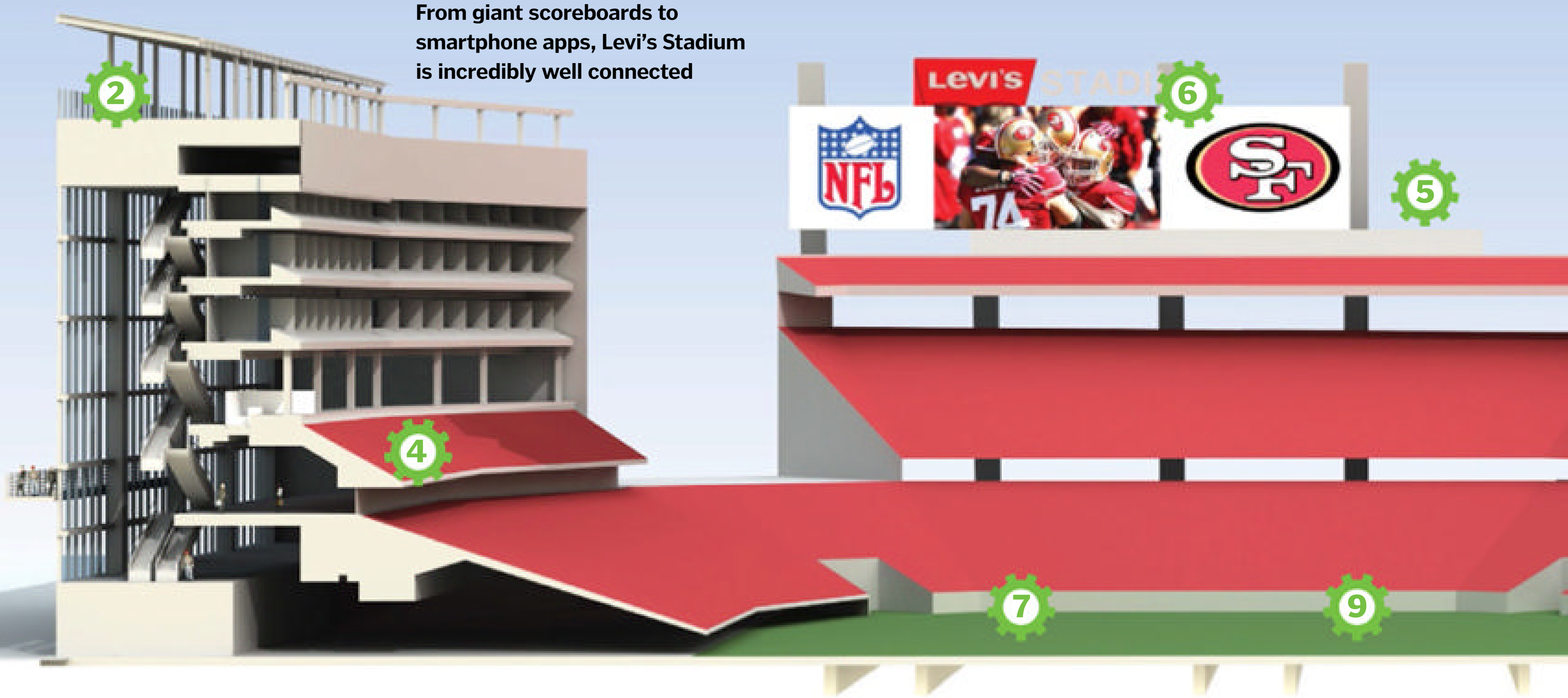
When the Mississippi River Bridge in Minneapolis, Minnesota collapsed in 2007 one of the key features of its replacement – the Saint Anthony Falls Bridge – was the ability to monitor the condition of the bridge so it could never happen again. The $234 (£150)-million bridge took under a year to complete and is now known as 'America's smartest bridge'. The 371-metre (1,216-foot)-long bridge contains a number of sensors that measure the amount of movement caused by weather, air temperature and traffic. It then transmits this data to Minnesota University. Accelerometers are also placed at the mid-point of each girder to check for excessive vibrations.

# SMART STADIUMS

The rise of sport on TV and internet streaming is making it tougher for sports teams to lure fans to the stadium, but the new home of the San Francisco 49ers, the Levi's Stadium, could turn the tide. This $1.2-billion (£788-million) American football stadium is packed to the rafters with amazing technology, such as 4K televisions, Wi-Fi access for all and an app that guides you to your seat. All this tech is aimed at getting fans off the sofa and to the ground by offering the multimedia experience they can enjoy at home while savouring the atmosphere only live entertainment can bring. ▶

## Levi's screens

**From giant scoreboards to smartphone apps, Levi's Stadium is incredibly well connected**



### 1 Seat finder

The app can detect where you are and guide you to the entrance nearest your seat.

### 2 Solar power

1,858m2 (20,000ft2) of solar panels are capable of providing the energy for all ten of the team's home games each year.

### 3 On the box

70 4K televisions are installed in the executive suites with a further 2,000 Sony TVs around the stadium.

### 4 On-the-go food

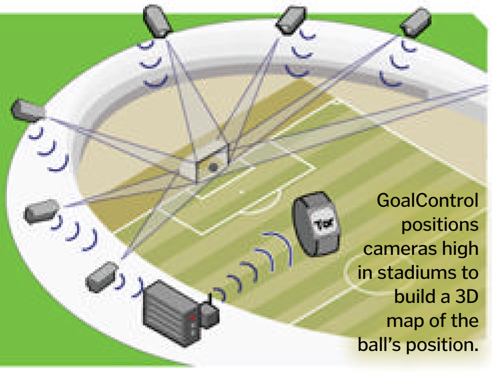
You can order food via the app, which will be delivered to your seat.

### 5 Wi-Fi connectivity

An incredible 40Gb/s of bandwidth can service speedy Wi-Fi access for 60,000 fans.

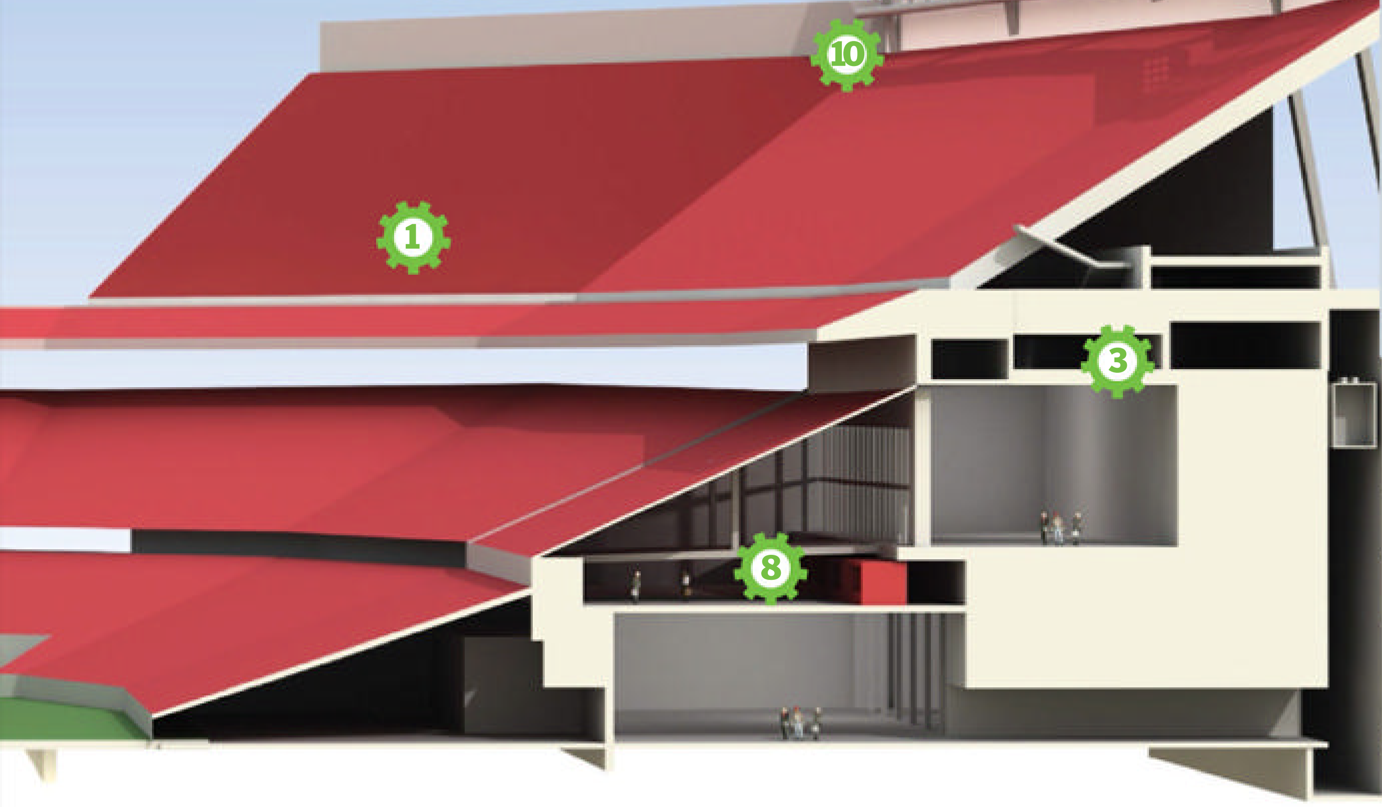
## Goal-line technology

The clamour for goal-line technology in football became too loud for FIFA to ignore following the 2010 World Cup, so several methods were trialled. Hawk-Eye and GoalControl employ 14 high-speed cameras running at 500 frames per second to follow the ball all game, building up a 3D image of its position on the pitch. If the ball crosses the line a signal is sent to the referee's watch. Other systems such as Cairos GLT and GoalRef use a combination of magnetic fields and electronics. The goal is surrounded by low magnetic fields and the ball contains an electronic circuit. The ball's circuit causes a measurable change in the magnetic field when it enters the goal. Sensors detect this change and instantly alert the referee.



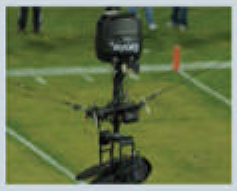
GoalControl positions cameras high in stadiums to build a 3D map of the ball's position.

**DID YOU KNOW?** *France's Karim Benzema scored the first goal-line-tech confirmed goal, at the 2014 World Cup against Honduras*



## Skycam

Skycam is a Sony HDC-P1 camera hooked up to a Steadicam harness. This harness is secured by four cables that stretch to each corner of a stadium. These are manipulated to allow the camera to rise, fall, rotate 360 degrees and track action at up to 40 kilometres (25 miles) per hour. The 23-kilogram (50 pound) device also contains an obstacle avoidance system that detects a hazard and automatically re-adjusts. It can even broadcast live action in 3D.



If there is an aerial shot of the game then chances are a Skycam took it

**6 Scoreboards** The stadium has two huge LED-lit scoreboards. The larger is 61 x 14.6m (200 x 48ft).

**7 Instant replays** If you've missed anything you can get instant replays on your phone.

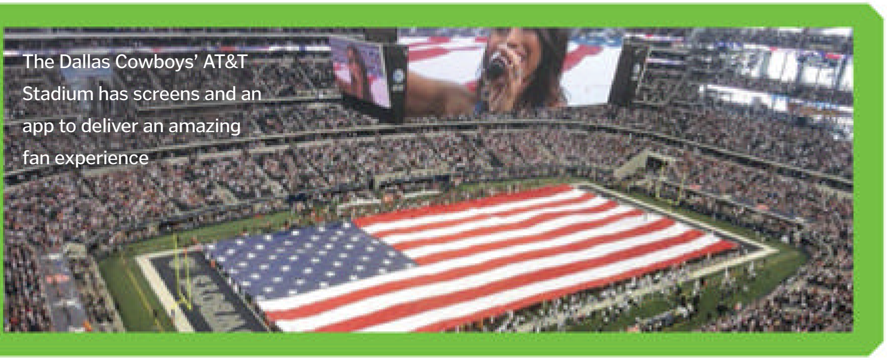
**8 Bathrooms breaks** The app also helps you find the food stands and bathrooms with the shortest queues.

**9 Eco-grass** The Bermuda Bandera grass uses 50 per cent less water than normal grass.

**10 Access points** There are 1,500 internet access points in the stadium, more than double than the amount at last year's Super Bowl venue.

## Appy and you know it

Stadiums are starting to use apps to enhance the fans' experience. The Levi's Stadium app allows fans to order food and drink, find seats and toilets and watch instant replays. The Wembley Stadium app displays the view from a particular seat before the ticket is bought and features a travel planner. The Dallas Cowboys have gone for the entertainment angle, using the Wi-Fi connection to sync up all users' smartphones and create a light show.

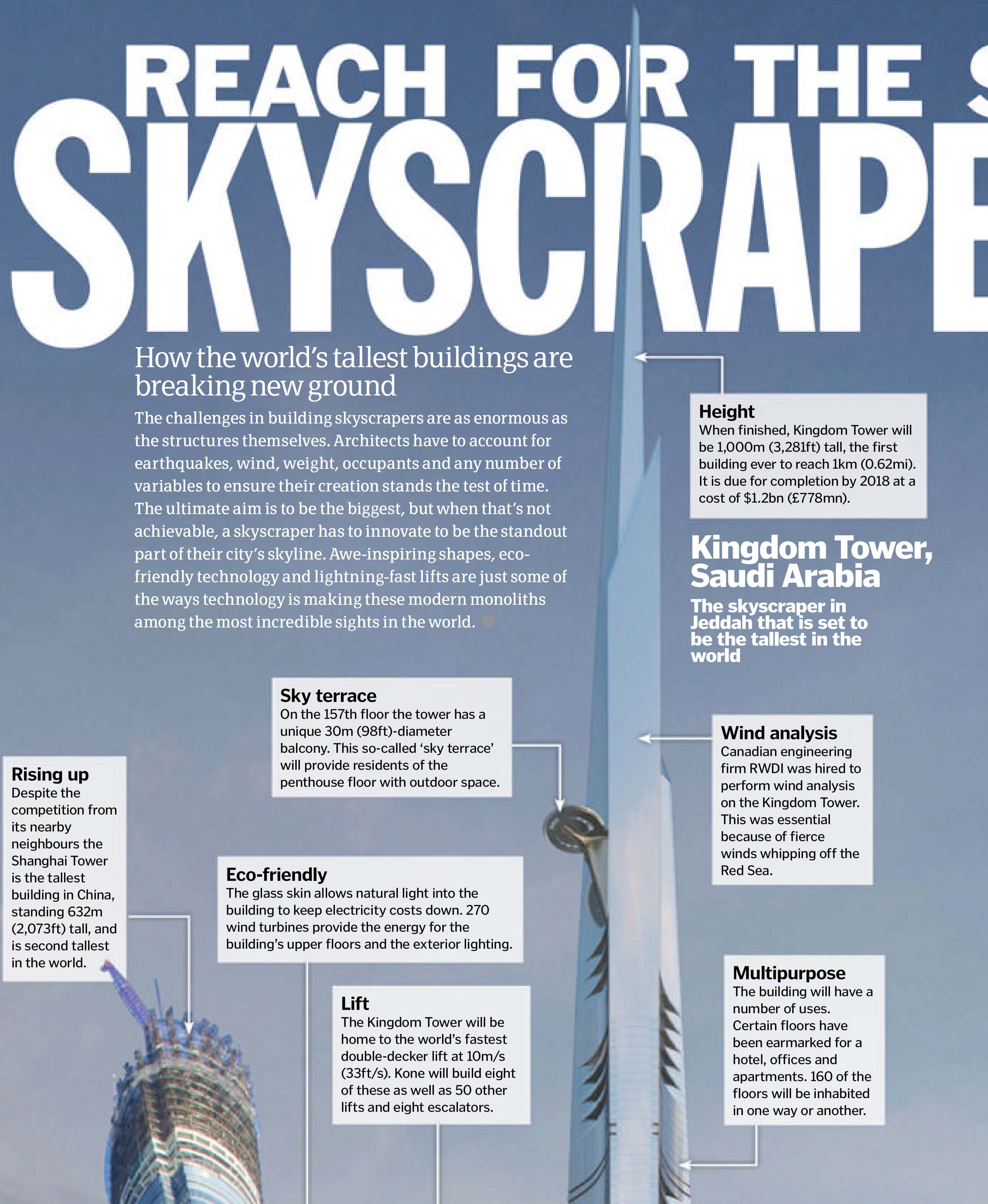


The Dallas Cowboys' AT&T Stadium has screens and an app to deliver an amazing fan experience

# REACH FOR THE SKY SKYSCRAPERS

## How the world's tallest buildings are breaking new ground

The challenges in building skyscrapers are as enormous as the structures themselves. Architects have to account for earthquakes, wind, weight, occupants and any number of variables to ensure their creation stands the test of time. The ultimate aim is to be the biggest, but when that's not achievable, a skyscraper has to innovate to be the standout part of their city's skyline. Awe-inspiring shapes, eco-friendly technology and lightning-fast lifts are just some of the ways technology is making these modern monoliths among the most incredible sights in the world.



## Kingdom Tower, Saudi Arabia

**The skyscraper in Jeddah that is set to be the tallest in the world**

**Height**
When finished, Kingdom Tower will be 1,000m (3,281ft) tall, the first building ever to reach 1km (0.62mi). It is due for completion by 2018 at a cost of $1.2bn (£778mn).

**Sky terrace**
On the 157th floor the tower has a unique 30m (98ft)-diameter balcony. This so-called 'sky terrace' will provide residents of the penthouse floor with outdoor space.

**Wind analysis**
Canadian engineering firm RWDI was hired to perform wind analysis on the Kingdom Tower. This was essential because of fierce winds whipping off the Red Sea.

**Rising up**
Despite the competition from its nearby neighbours the Shanghai Tower is the tallest building in China, standing 632m (2,073ft) tall, and is second tallest in the world.

**Eco-friendly**
The glass skin allows natural light into the building to keep electricity costs down. 270 wind turbines provide the energy for the building's upper floors and the exterior lighting.

**Lift**
The Kingdom Tower will be home to the world's fastest double-decker lift at 10m/s (33ft/s). Kone will build eight of these as well as 50 other lifts and eight escalators.

**Multipurpose**
The building will have a number of uses. Certain floors have been earmarked for a hotel, offices and apartments. 160 of the floors will be inhabited in one way or another.

## Keeping still

A major consideration in the construction process for buildings in areas prone to earthquakes is how to make sure they stay standing. The Taipei 101 skyscraper in Taiwan has a 730-ton ball hanging from its roof which swings slightly when the building starts to shake, counteracting any movement and drastically reducing the amount of sway. Other buildings such as the Utah State Capitol (below) use a different system known as base isolation. Almost 300 rubber-topped isolator devices are installed under the floor of the Capitol, acting like a suspension system in order to keep the building stable during strong seismic events.

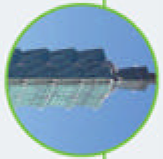
## KEY DATES
### LAST FIVE TALLEST BUILDINGS

**1972**
The original 417m (1,368ft)-high World Trade Center took the title from the Empire State Building.

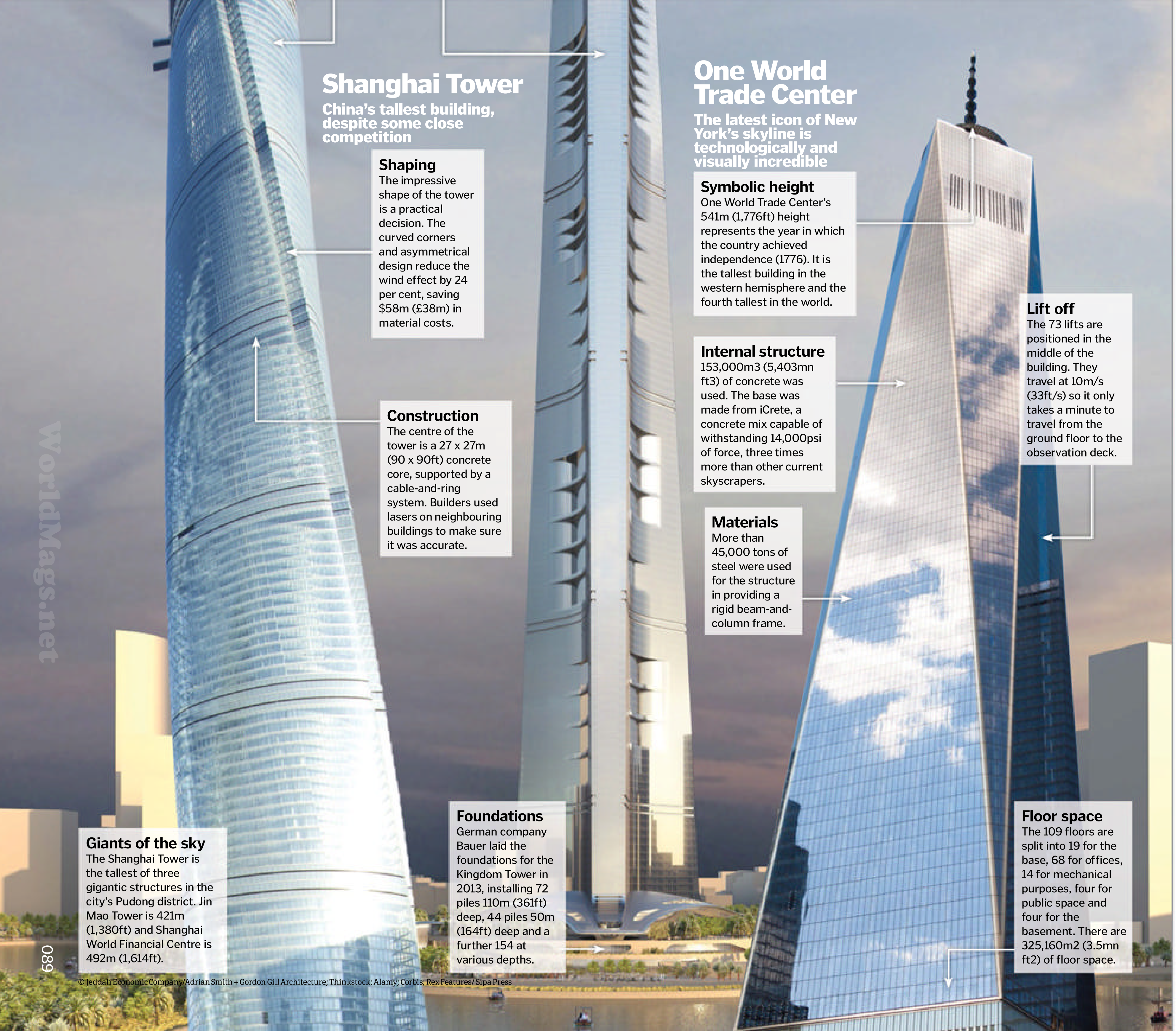
**1973**
In 1973 Willis Tower in Chicago, formerly known as the Sears Tower, became the world's tallest building at 442m (1,450ft).

**1998**
Malaysia's Petronas Towers became the record holder after a legal battle as the Willis Towers' antenna made the latter taller.

**2004**
Taipei 101 stands an impressive 509m (1,670ft) above the ground, taking the crown.



**2007**
Burj Khalifa has held the title since 2007, standing an incredible 828m (2,717ft) tall.



## Shanghai Tower
China's tallest building, despite some close competition

**Shaping**
The impressive shape of the tower is a practical decision. The curved corners and asymmetrical design reduce the wind effect by 24 per cent, saving $58m (£38m) in material costs.

**Construction**
The centre of the tower is a 27 x 27m (90 x 90ft) concrete core, supported by a cable-and-ring system. Builders used lasers on neighbouring buildings to make sure it was accurate.

**Giants of the sky**
The Shanghai Tower is the tallest of three gigantic structures in the city's Pudong district. Jin Mao Tower is 421m (1,380ft) and Shanghai World Financial Centre is 492m (1,614ft).

**Foundations**
German company Bauer laid the foundations for the Kingdom Tower in 2013, installing 72 piles 110m (361ft) deep, 44 piles 50m (164ft) deep and a further 154 at various depths.

## One World Trade Center
The latest icon of New York's skyline is technologically and visually incredible

**Symbolic height**
One World Trade Center's 541m (1,776ft) height represents the year in which the country achieved independence (1776). It is the tallest building in the western hemisphere and the fourth tallest in the world.

**Internal structure**
153,000m3 (5,403mn ft3) of concrete was used. The base was made from iCrete, a concrete mix capable of withstanding 14,000psi of force, three times more than other current skyscrapers.

**Materials**
More than 45,000 tons of steel were used for the structure in providing a rigid beam-and-column frame.

**Lift off**
The 73 lifts are positioned in the middle of the building. They travel at 10m/s (33ft/s) so it only takes a minute to travel from the ground floor to the observation deck.

**Floor space**
The 109 floors are split into 19 for the base, 68 for offices, 14 for mechanical purposes, four for public space and four for the basement. There are 325,160m2 (3.5mn ft2) of floor space.

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# Inside a spacesuit

## What's so special about an astronaut's outfit that it can keep them alive in space?

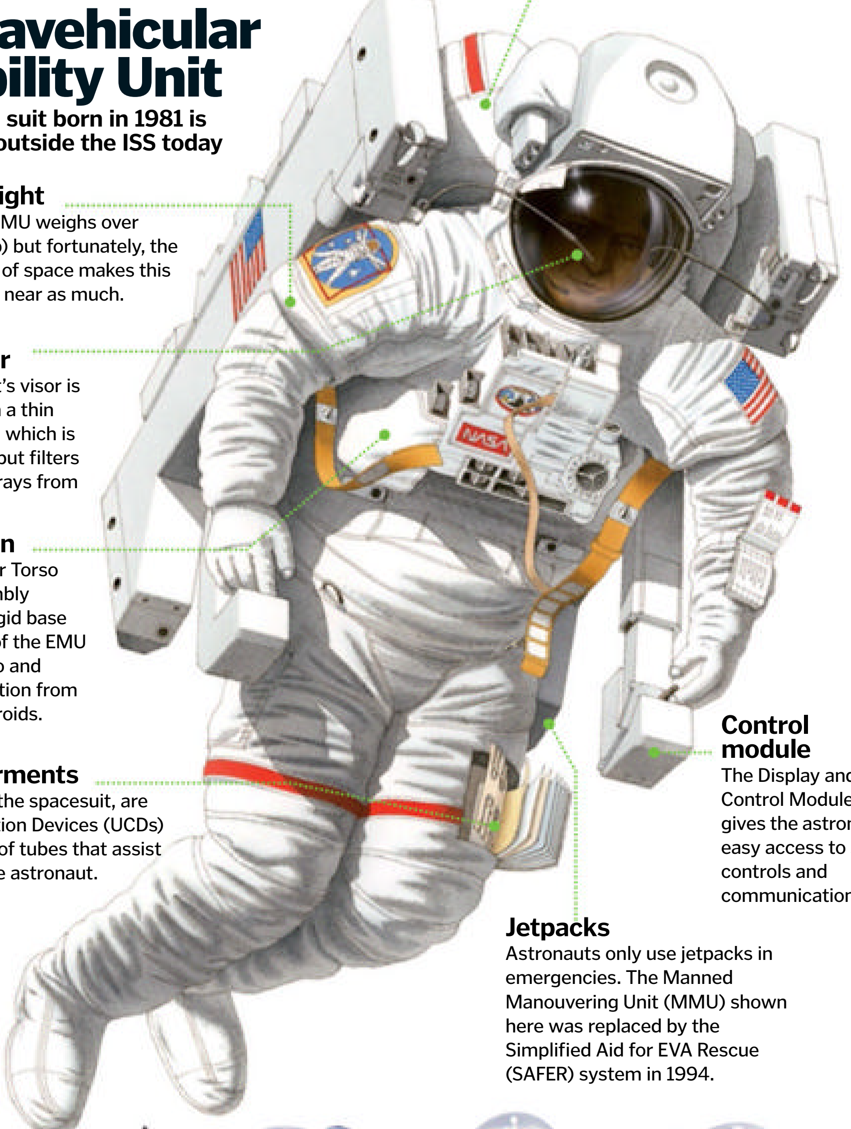
It's probably best to think of a spacesuit not as an item of clothing – like a jumper you'd put on when it's cold or a pair of wellies to keep your feet dry – but as a habitat or a small personal spaceship astronauts wear. Two of the main threats to human life in space are the lack of oxygen and the extreme range of temperatures, which can fluctuate from below -100 degrees Celsius (-150 degrees Fahrenheit) to in excess of 120 degrees Celsius (242 degrees Fahrenheit). But they can face other dangers, too: the extremely low pressure, micrometeorites travelling several times the speed of a bullet and exposure to high levels of radiation, unfiltered by any planetary atmosphere like Earth's, travelling from the Sun and deep space.

Astronauts need protection from these dangers while on an extravehicular activity (EVA) in space, so the modern spacesuit is designed to do just that. The outer section is divided into several main pieces with flexible and rigid parts, designed to provide mechanical protection from impact and a pressurised, oxygenated environment within the suit.

Underneath that, the astronaut wears a garment that helps regulate their body temperature with tubes that are woven into it, inside which water circulates for cooling. The astronaut's chunky backpack carries the primary life support subsystem, which pumps the oxygen into the astronaut's helmet for them to breathe and 'scrubs' the excess carbon dioxide out of the air they exhale. It also holds the electricity supply required to run the suit's systems and a water tank for the cooling system.

## Extravehicular Mobility Unit

**The space suit born in 1981 is still used outside the ISS today**



**Life support**
The heavy backpack contains power for the spacesuit, air and a water tank for cooling.

**Heavyweight**
A complete EMU weighs over 100kg (220lb) but fortunately, the microgravity of space makes this feel nowhere near as much.

**Gold layer**
An astronaut's visor is covered with a thin layer of gold, which is transparent but filters out harmful rays from the Sun.

**Protection**
A Hard Upper Torso (HUT) assembly provides a rigid base for the rest of the EMU to connect to and some protection from micrometeoroids.

**Undergarments**
Underneath the spacesuit, are Urine Collection Devices (UCDs) and a series of tubes that assist in cooling the astronaut.

**Control module**
The Display and Control Module gives the astronaut easy access to suit controls and communication.

**Jetpacks**
Astronauts only use jetpacks in emergencies. The Manned Manouvering Unit (MMU) shown here was replaced by the Simplified Aid for EVA Rescue (SAFER) system in 1994.

## The Z-suit

NASA's prototype Z-suit is a work in progress on an update to the current incarnation of the spacesuit, whose basic structure has been used for 30 years, ever since the Extravehicular Mobility Unit (EMU) was first made in 1981.

At a quick glance, the suit does not look radically different to contemporary space suits, however, looks can be deceptive because it has been designed to include several key features that will allow it to be used in both the microgravity of space and also for future missions to planets such as Mars, which the Apollo-era spacesuit is not capable of.

It can be quickly put on and taken off (astonishingly, current spacesuits can take an hour or even longer to put on) and include a suitport dock, which replaces the airlock on a spacecraft. This means that the spacecraft and space suit would be kept at the same pressure, so astronauts would not need to pre-breathe oxygen for at least 30 minutes before an EVA as they currently do in order to prevent decompression sickness.

© DK images; NASA

**THE STATS**
**CLAAS-Y NUMBERS**

WEIGHT 18,920kg

CAPACITY 12,500l

BLADES 108

HEADER WIDTH 12.3m

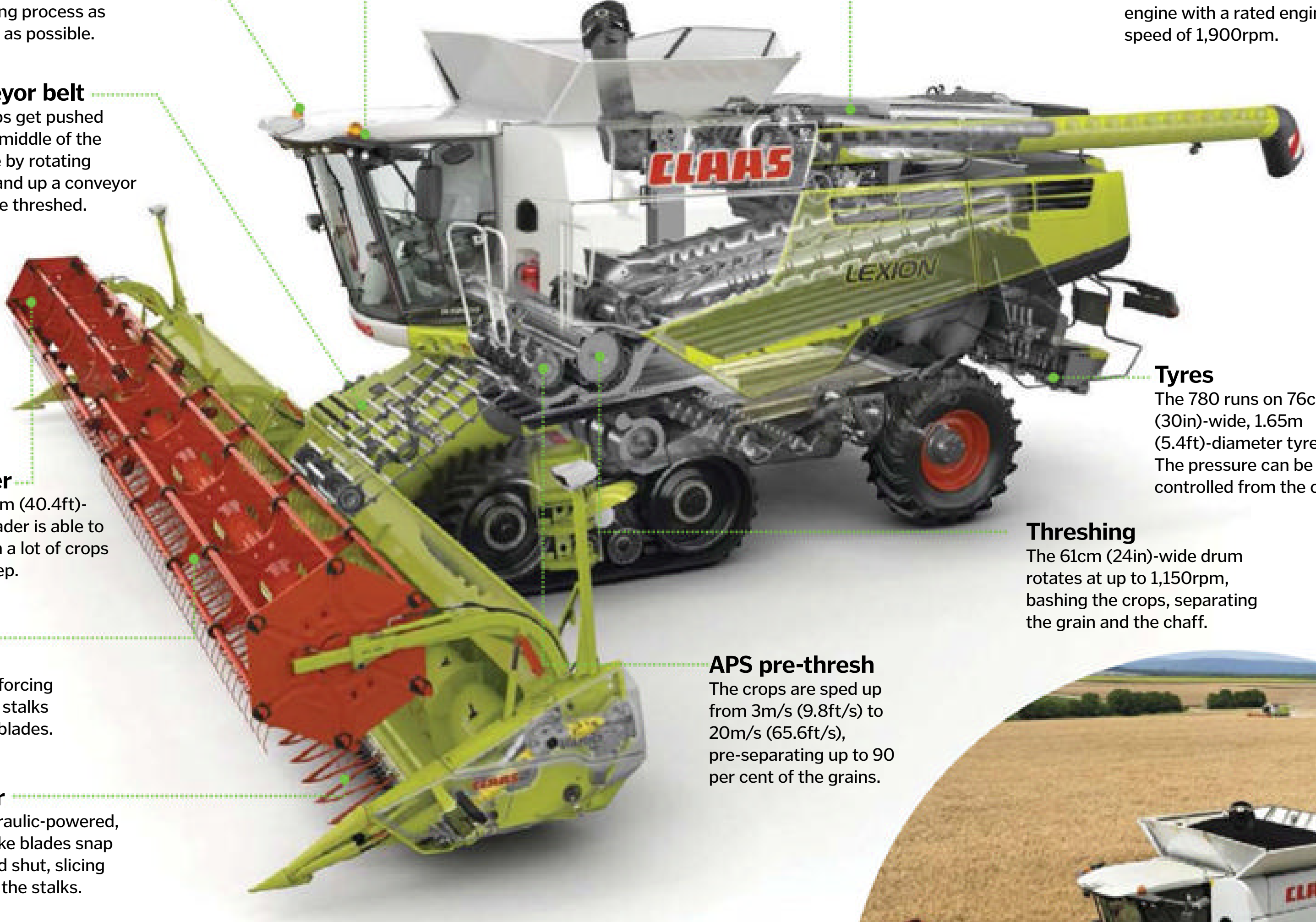
TYRE HEIGHT 1.65m

TOP SPEED 30km/h

**DID YOU KNOW?** The combine harvester has around 17,000 different parts, nearly three times as many as a standard car

# Inside a combine harvester

## How the Lexion 780 separates the wheat from the chaff



**GPS**
Satellites track where the machine is and where it has been to make the harvesting process as efficient as possible.

**Conveyor belt**
The crops get pushed into the middle of the machine by rotating screws and up a conveyor belt to be threshed.

**Header**
The 12.3m (40.4ft)-wide header is able to gather in a lot of crops per sweep.

**Reel**
The reel rotates, forcing the crop stalks into the blades.

**Cutter**
108 hydraulic-powered, pincer-like blades snap open and shut, slicing through the stalks.

**Comfort cab**
The cab's leather seat contains sweat-wicking technology and its suspension system absorbs 40 per cent of vibrations.

**Engine**
The 780 is powered by a V8 Mercedes-Benz OM 502 engine with a rated engine speed of 1,900rpm.

**Tyres**
The 780 runs on 76cm (30in)-wide, 1.65m (5.4ft)-diameter tyres. The pressure can be controlled from the cab.

**Threshing**
The 61cm (24in)-wide drum rotates at up to 1,150rpm, bashing the crops, separating the grain and the chaff.

**APS pre-thresh**
The crops are sped up from 3m/s (9.8ft/s) to 20m/s (65.6ft/s), pre-separating up to 90 per cent of the grains.

© CLAAS; Lexion

## How the combine harvester changed farming

Right up until the early-19th century harvests were taken in by hand. Teams of workers would slice the wheat stalks with scythes before pummelling the grain out of the husk.

The first method of transport that entered the fields was the reaper. The reaper, essentially the header, was pushed through the field by a team of horses. It sliced at the base of the stalks, which were then pushed out of a chute into a waiting wagon. The wagon would then take the crops to a central threshing machine that would beat the grain out of the stalks.

The modern combine harvester can be traced back to the 1830s when Hiram Moore combined the two machines, aiming to create an all-in-one reaper and thresher. It was not accepted for many years until its true value was recognised, where it became the subject of a raft of lawsuits from various people claiming to have originally invented it.

# The Empire State Building

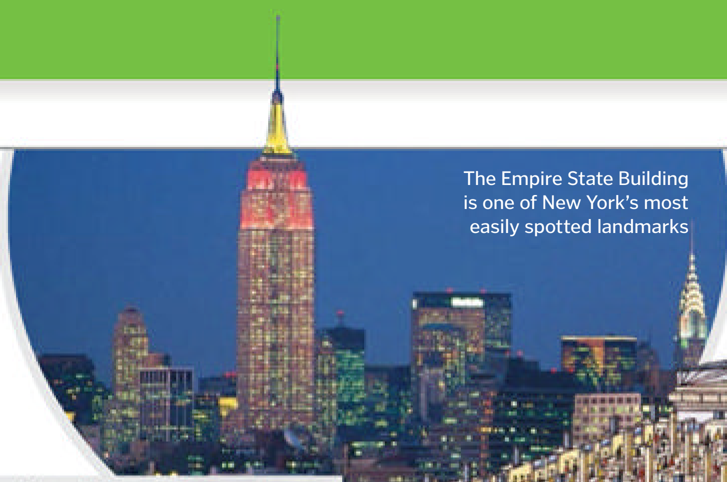
## How this US icon came to tower over New York City

With 103 floors and a 56-metre (185-foot) spire, the Empire State Building is an incredible 443.2 metres (1,454 feet) high. The world's tallest skyscraper when it was opened on 1 May 1931, it pipped New York's beautiful 319-metre (1,046-foot) Chrysler Building to the record and held onto it until 1970, when New York City saw the World Trade Centre spring from the pavement. They certainly build them big in the Big Apple and for 40 years, the Empire State Building was the biggest of them all.

The invention of steel framing in the late-19th century had made it possible for buildings to be taller than ever. While brick would eventually collapse under its own weight if you piled on too many floors, a honeycomb-like frame of steel beams could take the strain and spread the pressure of the upper floors throughout the building. Another 19th-century development – the elevator – raised the limit on how many storeys you could put on a building, for the simple reason that you can't expect someone to walk up 102 flights of stairs.

Construction began in March 1930. Financed by two former General Motors executives, John J Raskob and Pierre S du Pont, they applied the same revolutionary style of working that they'd used in the factory, with assembly lines of men putting the building together in shifts. However, without the benefit of modern cranes and lifting equipment, materials were hoisted up by pulleys and moved around the inside of the building on narrow railway tracks.

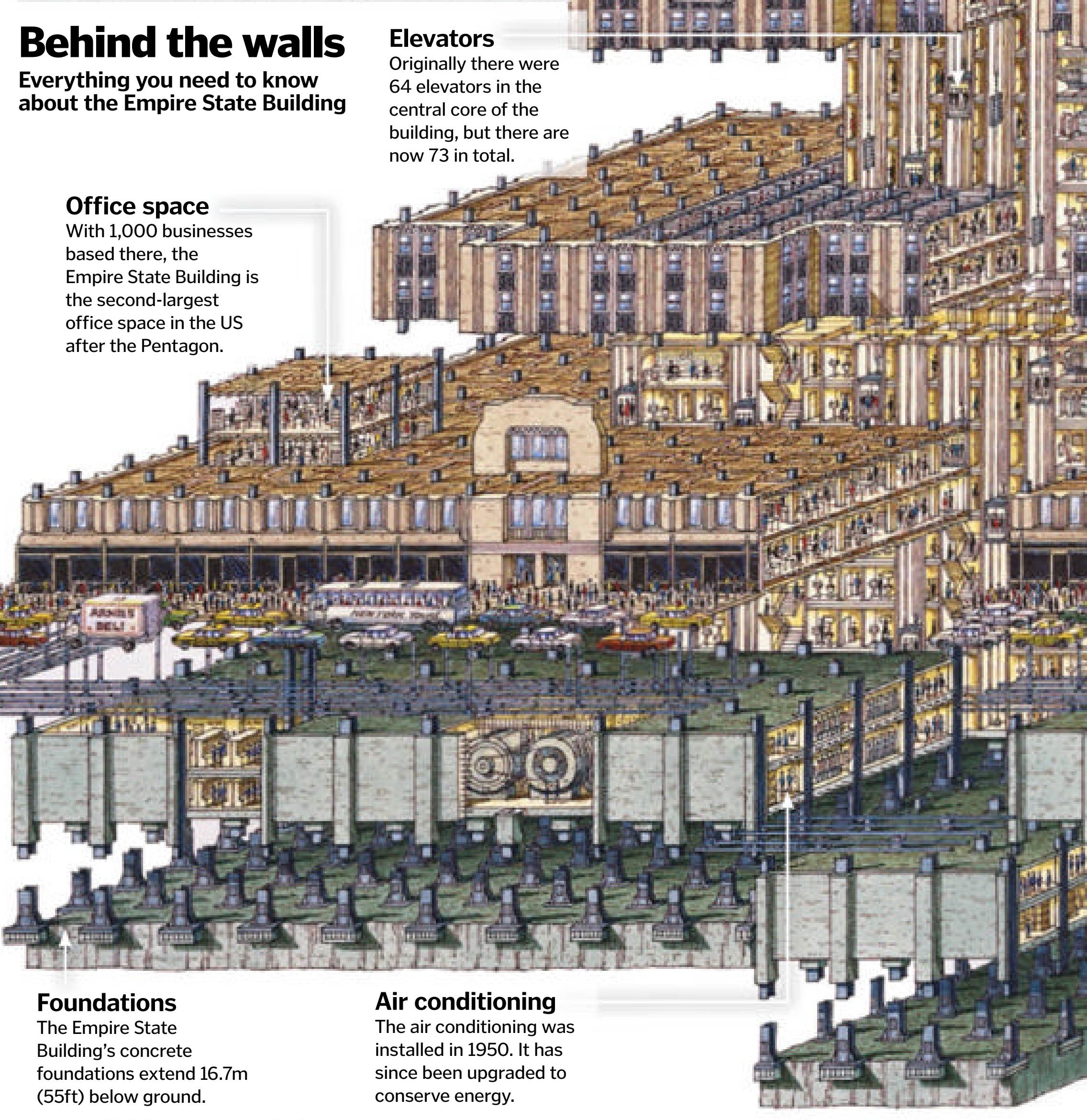
As many as 3,500 workers were on the building at once, many of them (known as 'sky boys') balancing on beams high above the city with no harnesses or helmets. It would be considered incredibly dangerous and reckless today, but those conditions were accepted as part of the job in 1930. After all, only five people died in the 410 days of its construction…


The Empire State Building is one of New York's most easily spotted landmarks

The 'sky boys' put their lives on the line

### Behind the walls

**Everything you need to know about the Empire State Building**



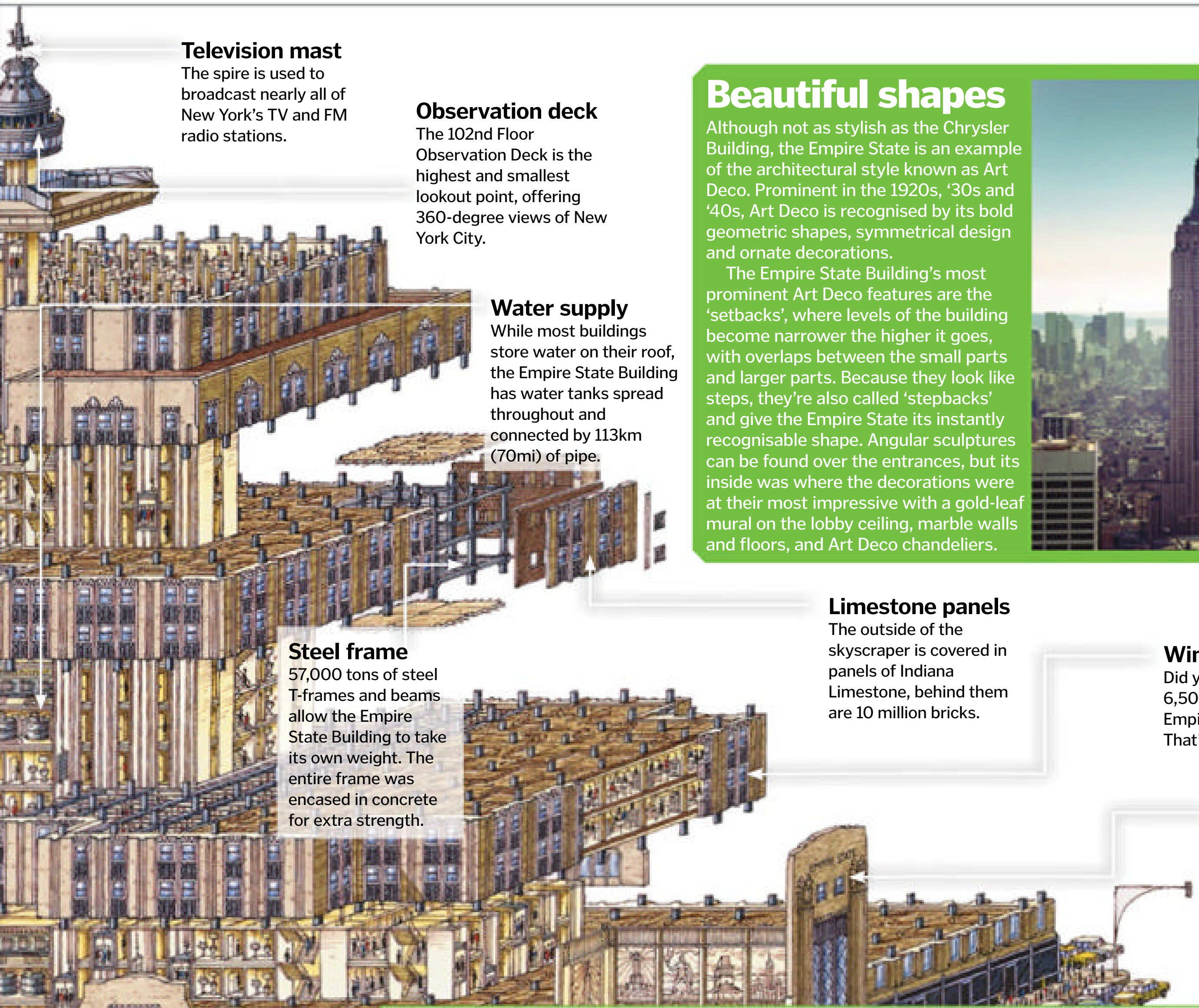
**Elevators**
Originally there were 64 elevators in the central core of the building, but there are now 73 in total.

**Office space**
With 1,000 businesses based there, the Empire State Building is the second-largest office space in the US after the Pentagon.

**Foundations**
The Empire State Building's concrete foundations extend 16.7m (55ft) below ground.

**Air conditioning**
The air conditioning was installed in 1950. It has since been upgraded to conserve energy.

**DID YOU KNOW?** *The Empire State owns the longest survived elevator fall after Betty Lou Oliver plummeted 75 storeys in 1945*



**Television mast**
The spire is used to broadcast nearly all of New York's TV and FM radio stations.

**Observation deck**
The 102nd Floor Observation Deck is the highest and smallest lookout point, offering 360-degree views of New York City.

## Beautiful shapes

Although not as stylish as the Chrysler Building, the Empire State is an example of the architectural style known as Art Deco. Prominent in the 1920s, '30s and '40s, Art Deco is recognised by its bold geometric shapes, symmetrical design and ornate decorations.

The Empire State Building's most prominent Art Deco features are the 'setbacks', where levels of the building become narrower the higher it goes, with overlaps between the small parts and larger parts. Because they look like steps, they're also called 'stepbacks' and give the Empire State its instantly recognisable shape. Angular sculptures can be found over the entrances, but its inside was where the decorations were at their most impressive with a gold-leaf mural on the lobby ceiling, marble walls and floors, and Art Deco chandeliers.

The Empire State Building is the world's most famous Art Deco building

**Water supply**
While most buildings store water on their roof, the Empire State Building has water tanks spread throughout and connected by 113km (70mi) of pipe.

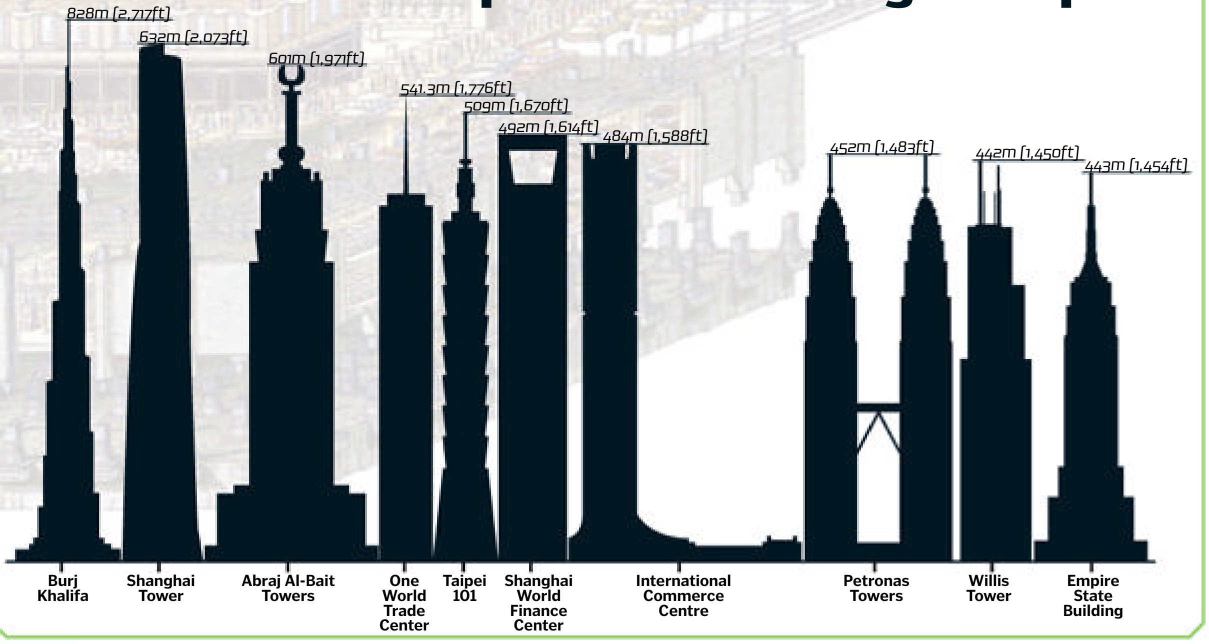
**Limestone panels**
The outside of the skyscraper is covered in panels of Indiana Limestone, behind them are 10 million bricks.

**Steel frame**
57,000 tons of steel T-frames and beams allow the Empire State Building to take its own weight. The entire frame was encased in concrete for extra strength.

**Windows**
Did you know there are 6,500 windows in the Empire State Building? That's a lot of cleaning!

**Entrance**
The main entrance has a 9.1m (30ft) high frontage with diamond-shaped frames of glass and two carved eagles on pillars.

## How does the Empire State Building size up?



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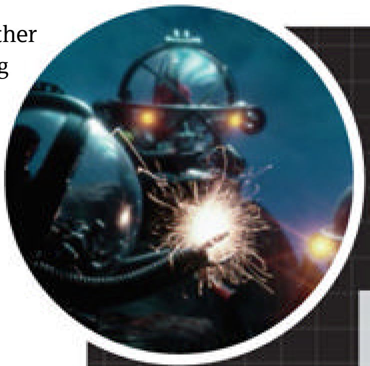
# How do we weld underwater?

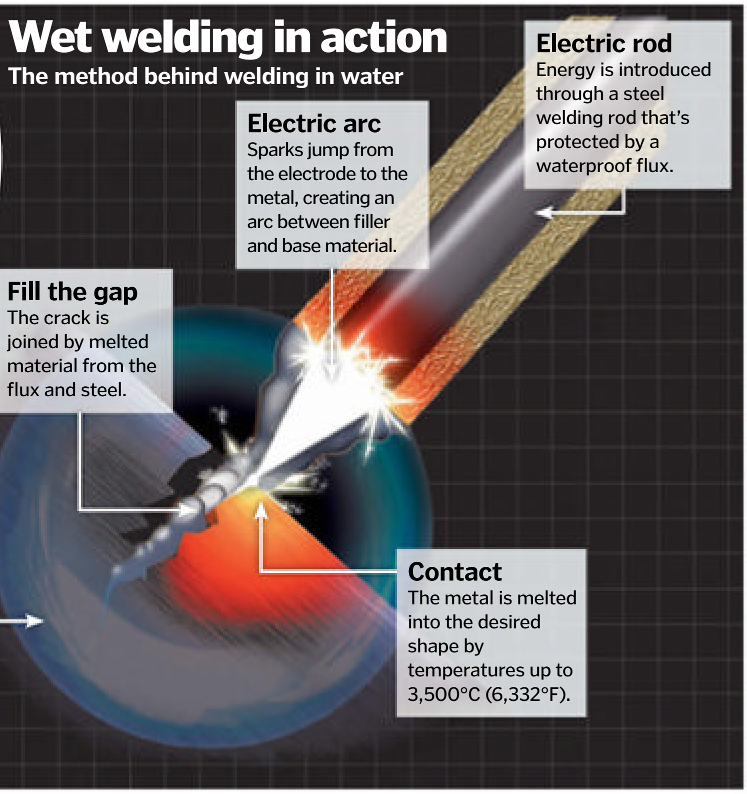
Find out how we patch up holes in vessels and pipes in a watery environment

Joining and fusing materials together has been a key part of engineering for centuries, but what about doing it underwater? High-pressure welding, more formally called hyperbaric fabrication, can now be undertaken in water in two ways.

Dry welding is done in a closed chamber, while wet welding can join metals completely exposed to water. An example of a dry welder is the Deep Rover submersible. Primarily used for exploration, this vehicle can hold up to two people in a sealed sphere and is capable of lifting chunks of metal too. Wet welding, on the other hand, creates a bubble of carbon dioxide around the weld point while the repair is made. Dry welding is safer due to the added protection but tends to be more expensive and time-consuming. Therefore, dry is better for larger, more involved projects while wet is generally used for smaller tasks. Both are used primarily to repair marine structures and deep-sea pipelines and can also be carried out by robots. Welding temperatures can reach 3,500 degrees Celsius (6,330 degrees Fahrenheit).



Deep Rover carries out dry welding some 900m (3,000ft) underwater



## Wet welding in action

**The method behind welding in water**

**Electric rod**
Energy is introduced through a steel welding rod that's protected by a waterproof flux.

**Electric arc**
Sparks jump from the electrode to the metal, creating an arc between filler and base material.

**Fill the gap**
The crack is joined by melted material from the flux and steel.

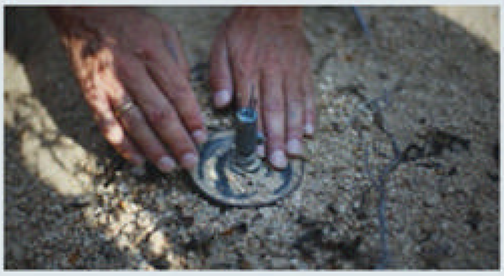
**Contact**
The metal is melted into the desired shape by temperatures up to 3,500°C (6,332°F).

**Bubble shield**
A byproduct of burning flux is carbon dioxide. This forms into a bubble shield, which holds back the seawater.

# What are jumping mines?

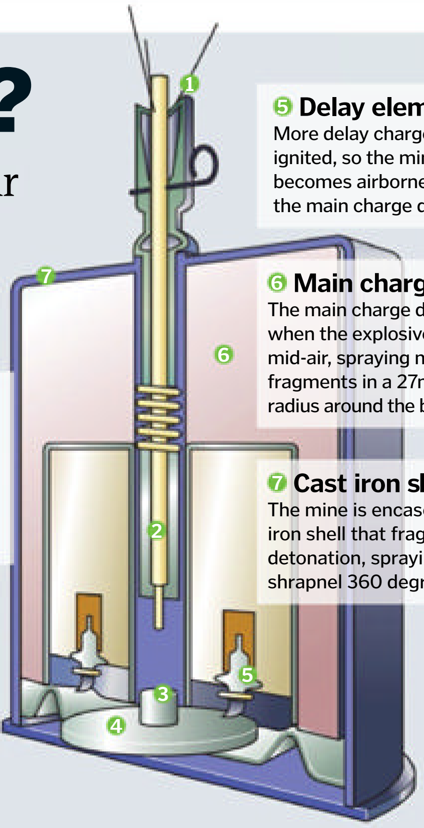
Discover how delay charges enable mines to detonate in the air

Bounding mines, like the German 'Bouncing Betty' and the US M16, differ from other anti-personnel mines as they explode in mid-air. When the fuse is activated, a propelling charge is fired, launching the mine out of the ground and, after a short delay, the main charge is detonated, showering its vicinity with shrapnel.



## Inside an M16 mine

**Bounding mines launch into the air before detonating to maximise their damage**



**① Prongs**
The three prongs of the fuse are pressure sensitive, so when stepped on or pulled by a tripwire, the firing pin is released.

**② Firing pin**
The spring-loaded firing pin crushes the explosives in the percussion cap, releasing hot gas and particulates that ignite the delay charge.

**③ Percussion cap**
A small delay charge activated by the percussion cap acts as a timer, allowing the target to move off before it detonates.

**④ Propelling charge**
The propelling charge is fired, launching the mine out of its casing into the air, reaching up to 1.7m (6ft) above the ground.

**⑤ Delay element**
More delay charges are ignited, so the mine becomes airborne before the main charge detonates.

**⑥ Main charge**
The main charge detonates when the explosive is in mid-air, spraying metal fragments in a 27m (89ft) radius around the blast zone.

**⑦ Cast iron shell**
The mine is encased in an iron shell that fragments on detonation, spraying shrapnel 360 degrees.

© DK Images; Corbis; Peters & Zabransky

# The compound bow

## Discover how new-and-improved technology has transformed the traditional bow and arrow into a whole new beast…

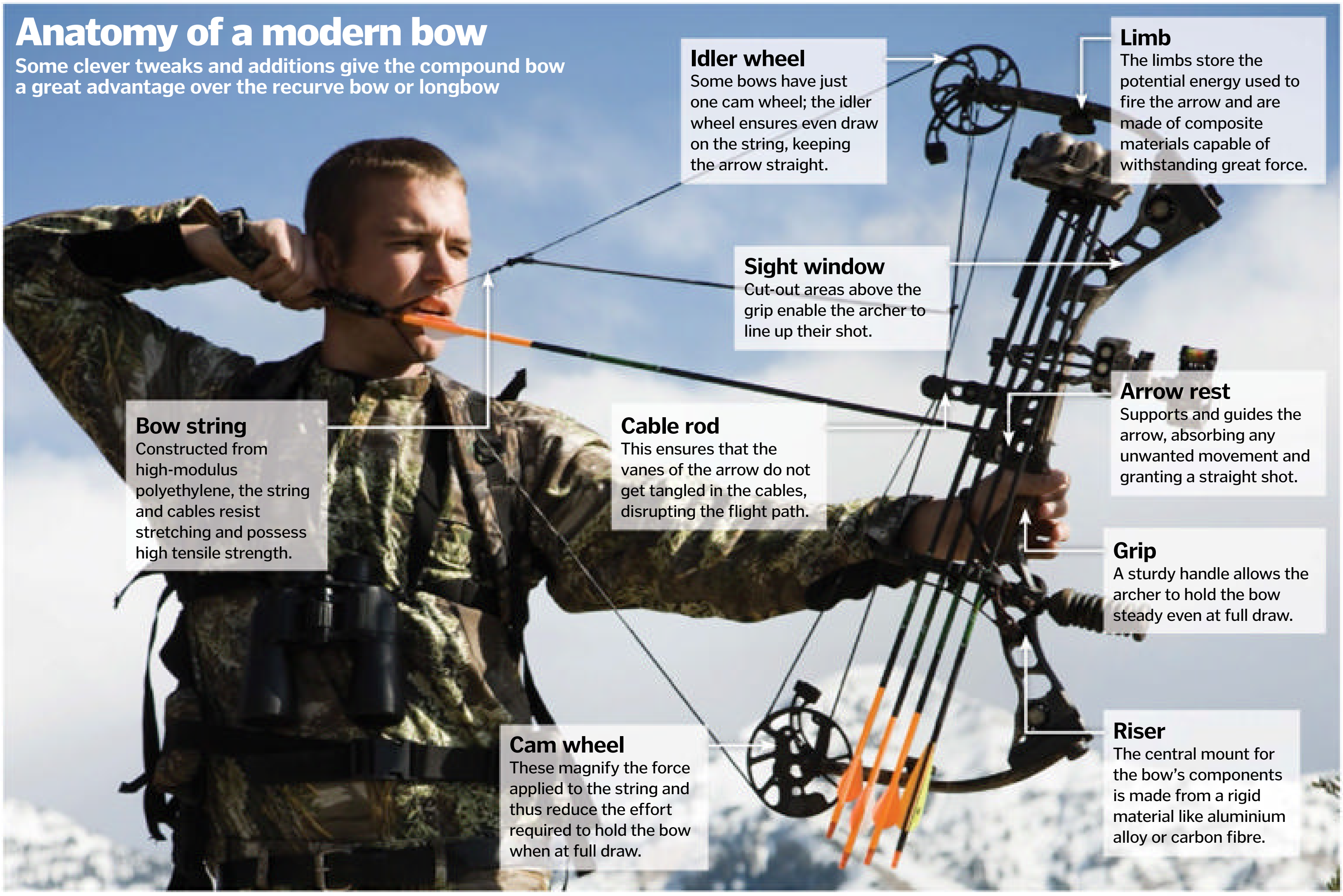
The power of the compound bow comes from its construction, comprising three components: a riser and two limbs. The riser is the central part of the bow that is held and is made of aluminium alloy, or carbon fibre, for maximum strength. The limbs are bolted to the riser and are made of a more flexible composite, allowing them to bend to store precious energy as the bow is drawn.

The stiffness of the limbs makes the compound bow much more energy efficient than other designs, with hardly any vibration. The composite construction also provides an advantage over wooden alternatives because it is much less affected by temperature and humidity, enabling the archer to shoot accurately in varying weather conditions.

However, the rigidity of the compound bow would make it incredibly hard to draw if the strings were attached directly to the limbs, so a pulley-driven levering system is used. As the string is drawn, the pulleys take in the cables, which draws the limbs of the bow together, storing energy. The system uses asymmetrical cams, so that as the string goes beyond 50-80 per cent of the draw length – towards the point at which the arrow is ready to fire – the amount of force needed to pull the string is reduced. This allows the archer to hold the bow at full draw for longer, granting steadier shooting.

## Beyond the bow…

To line up distant shots, archers often use sights with fibre-optic pins – different-coloured pins are set for varying distances, allowing the archer to adjust the shot. Scopes can also be added to magnify the target and increase aiming accuracy. Instead of using their fingers to draw the string, compound bow archers often use a mechanical release. Shaped like a small pincer, the release fits into the hand and pinches the string, enabling the bow to be fired more smoothly; using a release like this makes each shot much more consistent and predictable. Reducing vibration is also important in archery, as any unwanted movement will disturb the path of the arrow. Competitive archers and hunters often attach dampeners to the bow to nullify vibrating.



## Anatomy of a modern bow

Some clever tweaks and additions give the compound bow a great advantage over the recurve bow or longbow

**Idler wheel**
Some bows have just one cam wheel; the idler wheel ensures even draw on the string, keeping the arrow straight.

**Limb**
The limbs store the potential energy used to fire the arrow and are made of composite materials capable of withstanding great force.

**Sight window**
Cut-out areas above the grip enable the archer to line up their shot.

**Arrow rest**
Supports and guides the arrow, absorbing any unwanted movement and granting a straight shot.

**Bow string**
Constructed from high-modulus polyethylene, the string and cables resist stretching and possess high tensile strength.

**Cable rod**
This ensures that the vanes of the arrow do not get tangled in the cables, disrupting the flight path.

**Grip**
A sturdy handle allows the archer to hold the bow steady even at full draw.

**Cam wheel**
These magnify the force applied to the string and thus reduce the effort required to hold the bow when at full draw.

**Riser**
The central mount for the bow's components is made from a rigid material like aluminium alloy or carbon fibre.

© Corbis

# How bridges are built

## The design and technology behind these fundamental structures

All over the globe, bridges come in many shapes and sizes. The humble structure was born by simply balancing a horizontal beam across two pillars. However, as demand grew, wider gaps needed to be crossed and more weight had to be carried. This created the need for arches. Utilised by the Ancient Romans, the arch shape could hold massive amounts of weight and was a revelation in creating larger and stronger bridges. However, arches could only reach a certain length. To cross larger expanses, even longer bridges have to be constructed. These are called suspension bridges. These work using a combination of compression and tension forces that run through a cable system. The road or 'deck' is laid out across these cables, which are strung together with the correct balance of the two forces so it won't buckle or snap under pressure. On most suspension bridges, a tower is placed at either end to take the strain and weight. Iconic examples of these bridges include the Golden Gate Bridge in San Francisco and England's Humber Bridge. Away from the road, bridges are also used for rail and water transport. These bridges are often even longer and stronger as they have to ferry water or huge freight and passenger trains or ferries over vast distances. Seven of the ten longest bridges in the world are located in China, with most of these being rail bridges. As technology and engineering improves, even-more expansive bridges could be in the pipeline. There has been talk of a bridge between England and France and a crossing through the Strait of Gibraltar connecting Europe and Africa. Although it may seem far-fetched, the 16-kilometre (ten-mile) Øresund Bridge that links Denmark and Sweden has demonstrated that cross-country bridges can be constructed successfully.

### The Millennium Bridge

**Why this famous London structure started swaying**

When a new bridge is designed and built, it is essential that all of its construction calculations are absolutely correct. If they are even slightly out, the entire structure could become perilously unstable. Take the Millennium Bridge in London, for instance. Opened in 2000, the bridge experienced sudden and very dangerous sideways movements after the huge crowds who crossed it caused it to sway under the pressure. The eventual solution was to use 91 dampeners underneath the bridge, which absorbed the kinetic energy of the pedestrians' movement and prevented it from wobbling. It reopened fully fixed in 2002 but at a cost of over £5 million ($8 million). An expensive mistake!

**Compression and tension**
The sheer length of suspension bridges means many forces act upon it. The bridge's job is to balance the forces and transfer them to a stronger area that can handle the pressure.

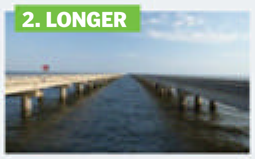
**Deck**
The deck can be made to suit road, rail or even water. It is strengthened by a truss that runs underneath the highway, allowing heavier weights to be transported across.

> "When a new bridge is made, it is essential that all of its construction calculations are correct. If they are even slightly out, the structure could become unstable"

## HEAD 2 HEAD
LONGEST BRIDGES

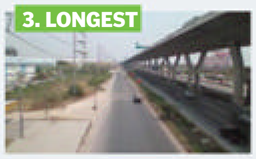
**1. LONG**

### Rio-Niteroi Bridge
This 13km (8mi) bridge connects Rio de Janeiro and Niterói in Brazil and saves residents a 100km (62mi) commute.



**2. LONGER**

### Lake Pontchartrain Causeway
Many bridges cross the US lake but the most gigantic of them is a huge 39km (24mi) long.

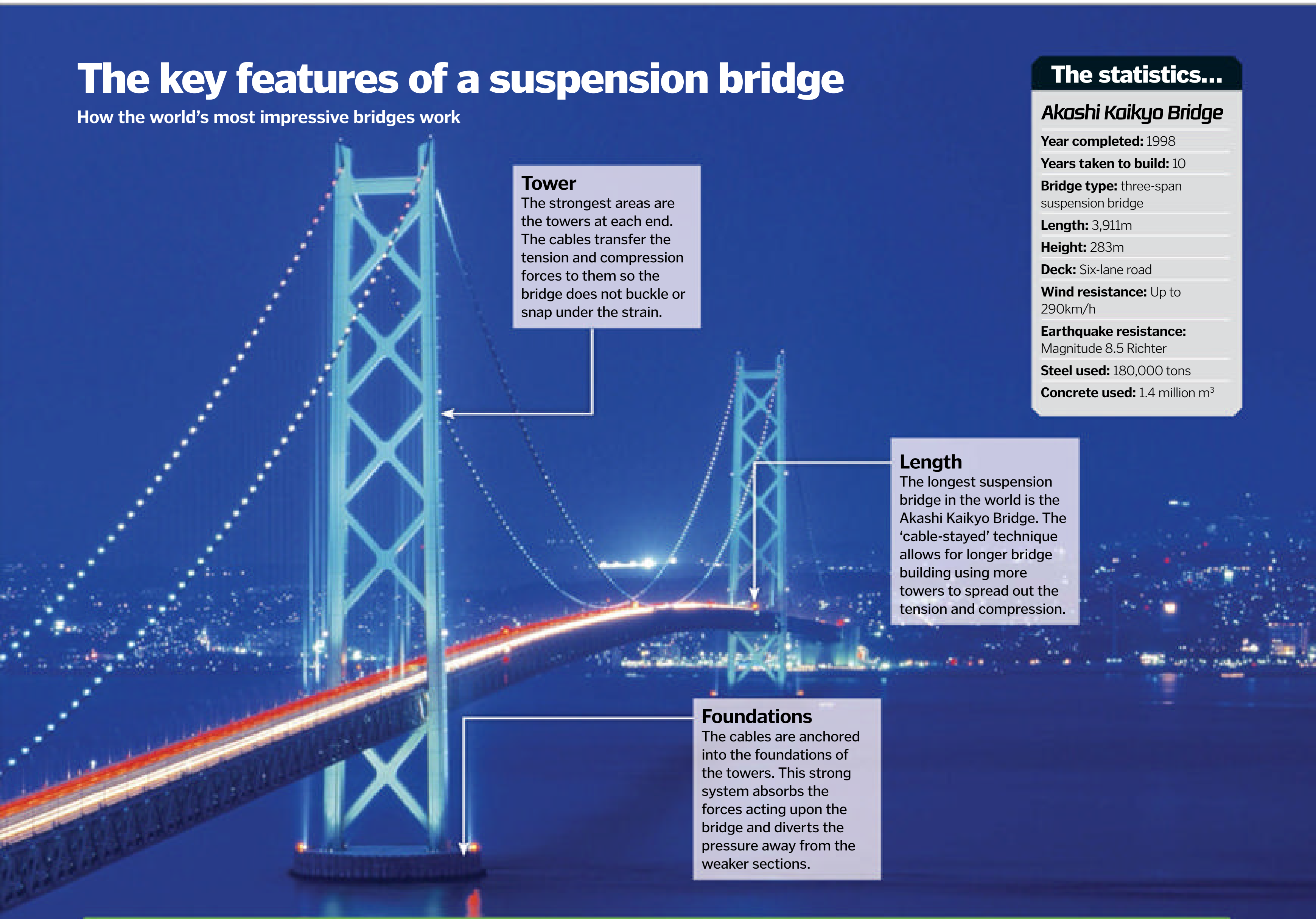


**3. LONGEST**

### Burapha Withi Expressway
This six-lane raised highway in Thailand is the longest road bridge in the world at a sprawling 55km (34mi) long.

**DID YOU KNOW?** *The world's first-ever iron bridge was officially opened in Shropshire, England in 1781*

# The key features of a suspension bridge
How the world's most impressive bridges work



### Tower
The strongest areas are the towers at each end. The cables transfer the tension and compression forces to them so the bridge does not buckle or snap under the strain.

### Length
The longest suspension bridge in the world is the Akashi Kaikyo Bridge. The 'cable-stayed' technique allows for longer bridge building using more towers to spread out the tension and compression.

### Foundations
The cables are anchored into the foundations of the towers. This strong system absorbs the forces acting upon the bridge and diverts the pressure away from the weaker sections.

### The statistics…
*Akashi Kaikyo Bridge*

**Year completed:** 1998

**Years taken to build:** 10

**Bridge type:** three-span suspension bridge

**Length:** 3,911m

**Height:** 283m

**Deck:** Six-lane road

**Wind resistance:** Up to 290km/h

**Earthquake resistance:** Magnitude 8.5 Richter

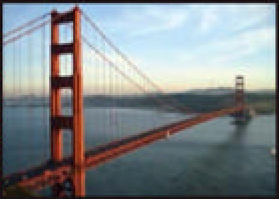
**Steel used:** 180,000 tons

**Concrete used:** 1.4 million m$^3$

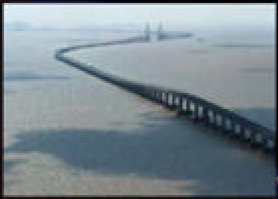
# Types of bridge
The many ways to bridge and cross a gap

### Arch
One of the oldest methods of bridge building, the arch bridge is made by compressing stone, steel and concrete with the finished arch working as a wind bracer. Arch bridges can range from small brick designs to tall and extensive metal constructions.

### Suspension
This type of bridge is made of steel plates and cables. Suspension bridges use a combination of tension and compression, which is carried by the cables to towers at either end. The cables transfer the weight to the towers. Their light weight allows them to span long distances.



### Beam
Made out of wood or iron, beam bridges are the simplest type of bridge construction. The weight is put on two support girders on either side of the crossing. The earliest examples of beam bridges came in the form of humble logs or tree trunks across streams and rivers.



### Cable-stayed
The cable-stayed bridge is one of the most common in contemporary bridge building. They have one or more towers, each of which uses vertical compression to move the forces from the cables through to the foundations, reducing the strain and stress on each part of the bridge.

### Bascule
Also known as a drawbridge, it ranges in size from a medieval feature to larger structures like Tower Bridge. Usually powered by a counterweight and winch, similar designs include a vertical-lift bridge that rises straight up and a swing bridge that can pivot horizontally to open up.

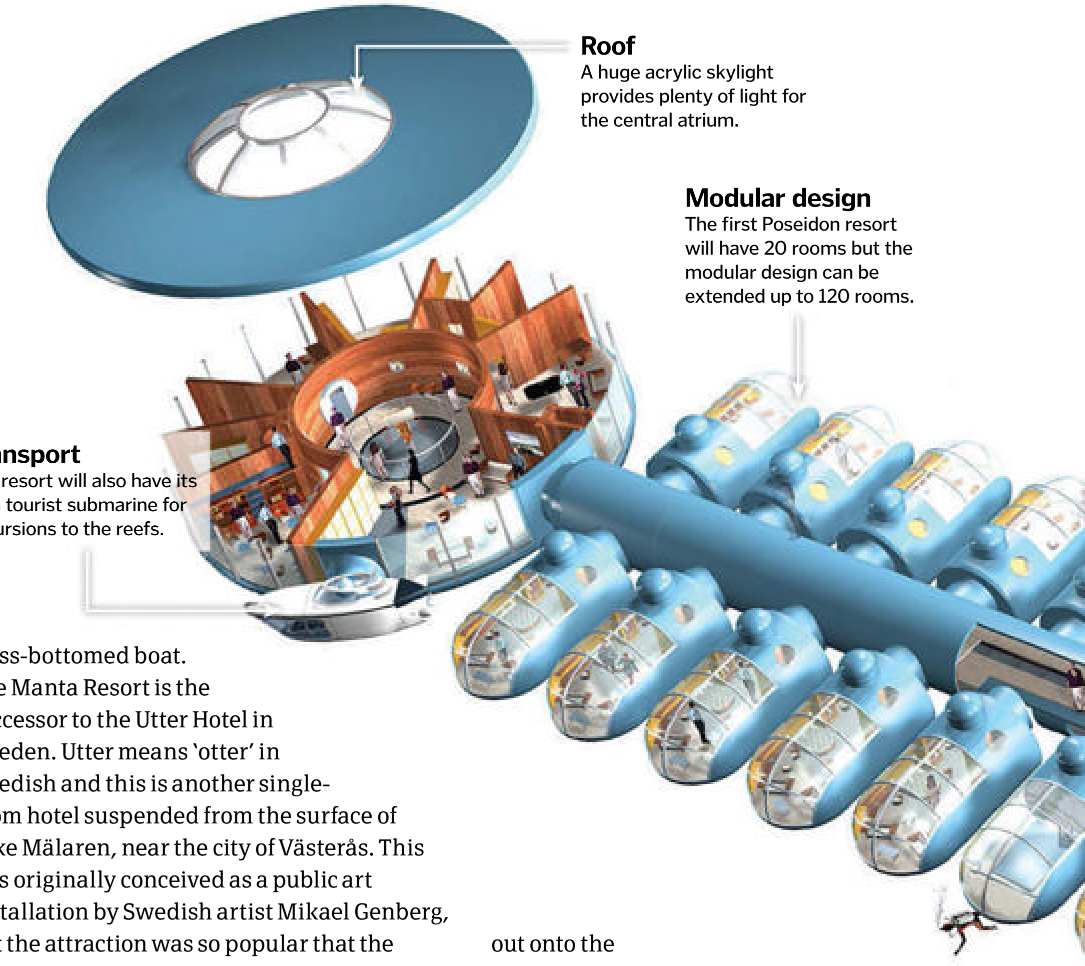
© Rich Niewiroski Jr; Thinkstock; Corbis

# Underwater buildings

## With land in short supply, it's little wonder more and more architects are looking beneath the waves for inspiration…

### A new Poseidon adventure

**One of the marine habitats currently under construction, take a tour around the Poseidon Undersea Resort now**



**Roof**
A huge acrylic skylight provides plenty of light for the central atrium.

**Modular design**
The first Poseidon resort will have 20 rooms but the modular design can be extended up to 120 rooms.

**Transport**
The resort will also have its own tourist submarine for excursions to the reefs.

Submarines have been around since at least the 18th century and modern nuclear subs can reach depths of over 400 metres (1,300 feet). By comparison, building a house just ten or so metres (33 feet) below the surface might seem easy by comparison, but permanent dwellings have their own set of unique challenges. Let's start at the front door. A submarine rises to the surface to let people on and off. This means the air inside the sub can be kept at normal atmospheric pressure. But a completely submerged building anchored to the seabed either needs an airlock, so the pressure can be adjusted as divers enter and exit, or it needs to keep its internal air pressure the same as the water pressure outside.

When you spend more than an hour or so breathing high-pressure air, the nitrogen in the air dissolves into the water stored in your body tissue. Without an extensive period of gradual decompression at the end of your stay, the nitrogen will come out of solution all at once and form bubbles that can cramp muscles and block blood vessels. This is a potentially lethal condition known as 'the bends'.

To avoid this risk, most undersea buildings currently being planned have a permanent access link to the surface. This allows the air pressure throughout the building to be kept at normal atmospheric levels, but it means that there is nothing balancing the huge weight of the water outside. At a depth of 20 metres (66 feet), each square metre of wall or window has more than 20 tons of weight pressing against it. This requires much thicker and stronger materials than a normal house, plus walls and roofs have to be curved to distribute the load evenly. A permanent connection to the surface also exposes the building to tidal forces.

The Underwater Room at Tanzania's Manta Resort is a single-bedroom hotel in the Zanzibar archipelago. To avoid the constant scouring of the twice-daily four-metre (13-foot) tides in the island chain, this room isn't firmly anchored to the seabed. Instead it hangs below an upper deck that floats on the surface. The effect is rather like an extreme version of a glass-bottomed boat. The Manta Resort is the successor to the Utter Hotel in Sweden. Utter means 'otter' in Swedish and this is another single-room hotel suspended from the surface of Lake Mälaren, near the city of Västerås. This was originally conceived as a public art installation by Swedish artist Mikael Genberg, but the attraction was so popular that the Genberg Underwater Hotels Company was formed in 2006 to bring the concept to warmer waters around the world.

More ambitious designs have floors raised entirely above the sea surface, as well as anchored below it, with the two levels connected by narrow support piles. The Water Discus Hotel is an ambitious project proposed for the Maldives that looks like a landed spaceship. The upper levels are supported high enough above the water to survive a medium-sized tsunami, while the undersea level sits ten metres (33 feet) deep with 21 bedrooms that look out onto the specially lit coral reef.

Dr Lech Rowinski chairs the Department of Theory and Ship Design at Gdansk University in Poland. He is a cofounder of Deep Ocean Technology, the company behind the Water Discus Hotel. In an exclusive interview with **How It Works**, he told us about the challenges of the project: "For us, wave action is the biggest problem, because we are necessarily limited to areas with low tidal ranges. We have the opposite design to an oil rig, where you build high above the water just to avoid the waves. In our case we have a

## 5 TOP FACTS AQUATIC ABODES

**Aquatica**

**1** An old submarine refuelling base is turned into a medical research base in *Deep Blue Sea* (1999). Surprisingly, breeding super-intelligent mutant sharks turns out to be a bad idea.

**Broken Ridge**

**2** In the Nineties TV series *seaQuest DSV*, land resources are exhausted and underwater mining towns line the ocean floor. Broken Ridge is off the coast of Australia.

**Tri-Oceanic Corp**

**3** In *Leviathan* (1989), undersea miners plan to spend 90 days at the bottom of the Atlantic Ocean. But then they find a contaminated shipwreck and start sprouting tentacles.

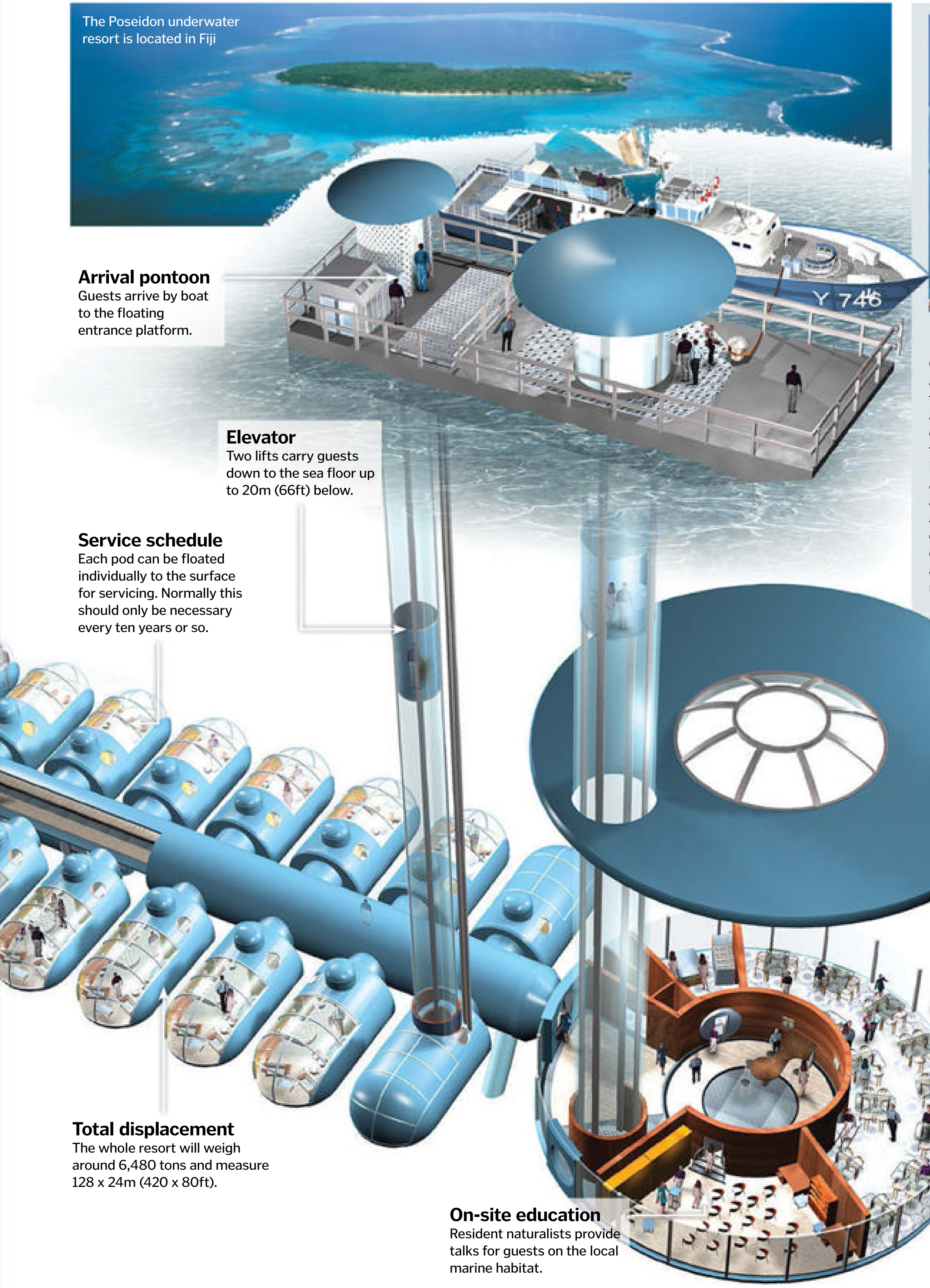
**Deep Core**

**4** The deep-sea platform in *The Abyss* (1989) sits an alarming 2km (1.2mi) under the sea. That's peanuts compared to the aliens living in the 8km (5mi) ocean trench though.

**Atlantis**

**5** Not just the lost city of Greek legend, but also the secret undersea lair of supervillain Karl Stromberg from the 1977 Bond movie *The Spy Who Loved Me*.

**DID YOU KNOW?** To hire the entire Poseidon Undersea Resort exclusively for a week will cost $2.75mn (£1.67mn)


The Poseidon underwater resort is located in Fiji

**Arrival pontoon**
Guests arrive by boat to the floating entrance platform.

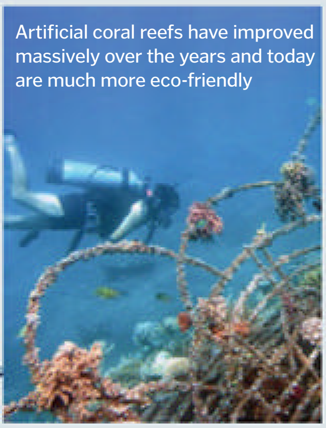
**Elevator**
Two lifts carry guests down to the sea floor up to 20m (66ft) below.

**Service schedule**
Each pod can be floated individually to the surface for servicing. Normally this should only be necessary every ten years or so.

**Total displacement**
The whole resort will weigh around 6,480 tons and measure 128 x 24m (420 x 80ft).

**On-site education**
Resident naturalists provide talks for guests on the local marine habitat.

**Acrylic windows**
Each curved pane in a Poseidon resort is 3 x 2m (10 x 6ft) and 10cm (4in) thick to withstand the external pressure.


Artificial coral reefs have improved massively over the years and today are much more eco-friendly

## Keeping green

Coral reefs are fragile structures and living polyps are very sensitive to pollution levels. In the Seventies, attempts to construct an artificial coral reef out of millions of old car tyres off the Florida coast turned into an environmental catastrophe as the tyres not only failed to attract new corals but broke loose and caused extensive damage to existing reefs. Modern undersea construction uses buildings anchored on piles so they have minimal contact with the seabed, using materials that encourage coral growth on their surface. All waste and effluent is recycled or removed in order to not contaminate the water.

substantial volume under the water so there are huge forces acting on it." Surprisingly, the solution is not to sink deep foundation piles into the bedrock. Instead the Water Discus Hotel will be anchored to the seabed using suction. It works a bit like a Wellington boot that gets stuck in deep mud, except that the mud in this particular case is a steel-walled cavity that the hotel base sits in. "It's a question of not allowing water *under* the structure," explains Dr Rowinski: "You have a cavity – it doesn't need to be water-tight, but with very limited flow. Pumping the water out isn't required because it is a dynamic system. One moment you have lower pressure at the bottom of the wave and another moment you have higher pressure, so you only need a small overall force keeping the base of the hotel in the cavity."

The walls of underwater buildings are made from steel, using shipbuilding techniques, but the large windows are made from acrylic plastic. It flexes slightly to avoid stress fractures, but more importantly it has a refractive index very similar to water, so it doesn't interfere with the view. It is also the reason underwater hotels are sited no deeper than 30 metres (98 feet) below the surface. "It's a question of visibility," says Dr Rowinski: "We need to provide some colour for objects in the water and if you want colour you need shallow water."

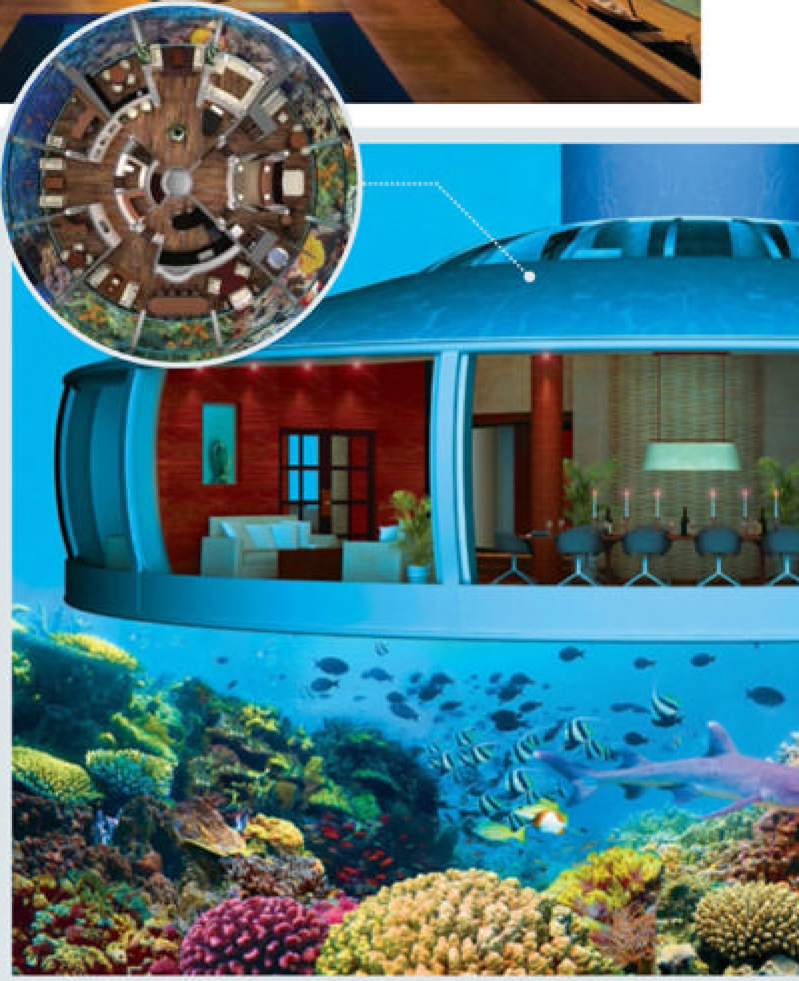
But even ten metres (33 feet) of water presents a significant problem in the event of an emergency evacuation. Ironically, fire safety is actually a major consideration in an aquatic building because even a small fire can quickly consume the available breathable air. The Water Discus Hotel is designed so that the entire underwater section can rise to the surface. Dr Rowinski explains: "We designed the ballast tanks above the water level so you can raise the structure easily, without the aid of any mechanical equipment. It rises under its own buoyancy. It would take at least 15 minutes to rise, but we think this is actually too fast, so we aim for half an hour. This is for organisation of the evacuation – to allow people to move without panicking."

And if you happen to be concerned about the risk of hurricanes or tropical storms, an underwater holiday might actually be the safest destination for you. "I think the hotel will be more resistant to weather than buildings on land," concludes Dr Rowinski: "In the Maldives, very high waves during tsunamis are very likely so it's safer to be in the underwater compartment than on the shore."

This underwater suite is part of a luxury hotel in the Maldives

## Ocean homes

While a week-long luxury holiday or research trip might be enough for most of us, if you want something more permanent, there are now a few companies that will build you a permanent undersea residence. US Submarine Structures LLC is currently constructing two-bedroom circular houses that can be anchored to the seabed of your choice. The '$H_2$OME' project can cope with depths between ten and 20 metres (33-66 feet) and is connected to the surface via a lift in the central pillar. This means the air inside the house is the same pressure as the surface, so there is no need for airlocks or lengthy decompression procedures when you leave. The panoramic acrylic windows extend around the house, offering views from every room. Each habitat features over 460 square metres (5,000 square feet) of living space, complete with luxury furnishings and décor inspired by five-star hotels and superyachts.



## Evolution of undersea habitats

**1962**

**Conshelf I**

Designed by Jacques Cousteau, the Continental Shelf Station is the first inhabited underwater building. Two 'oceanauts' spend a week in this 5 x 2.5m (16.4 x 8.2ft) cylinder.

**1964**

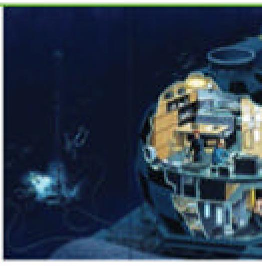
**SEALAB I**

Built by the US Navy to study techniques to reduce decompression sickness after diving for extended periods. It spends 11 days at 58m (190ft) depth.

**1965**

**Conshelf III**

The last of Cousteau's underwater habitats (right). At 100m (328ft) below the surface – ten times deeper than Conshelf I – it is self-sufficient for three weeks.



## THE STATS
**WATER DISCUS HOTEL SPECS**

ROOMS **21**

1,000m$^2$ **FLOOR AREA**

DEPTH **10m**

DIAMETER **49m**

**2017 COMPLETION DATE**

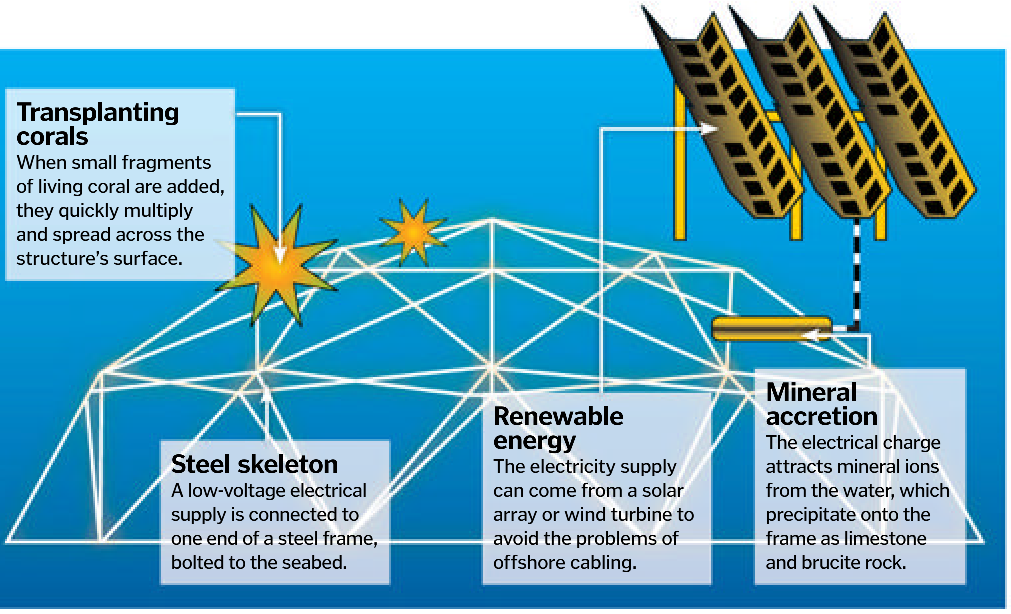
$50-120mn **ESTIMATED COST**

**DID YOU KNOW?** *In 1966, a Soviet amateur diving club built a series of underwater habitats (The Ichthyander Project) in the Black Sea*

## Make a living building

A coral reef is made mostly from calcium carbonate (limestone). The coral polyps living there absorb mineral ions from the seawater and deposit it as solid rock around their bodies to form an exoskeleton. Biorock harnesses these same mineral ions but uses electricity instead of living corals to precipitate them as solid rock. The electrically charged ions can be attracted onto a metal surface by running an opposite charge through the metal. This only needs a low voltage, harmless to marine life and by varying the current you can adjust the mineral formation.

In theory, Biorock could let us 'grow' a building (see diagram). Although it uses more energy to produce than ordinary concrete, it is three times stronger and can take any shape. The layer grows at up to five centimetres (two inches) a year and damage from storms or collisions can heal itself, provided the power stays on. And far from harming marine life, corals attached to Biorock actually grow faster and tolerate worse sea conditions than corals on natural reefs.



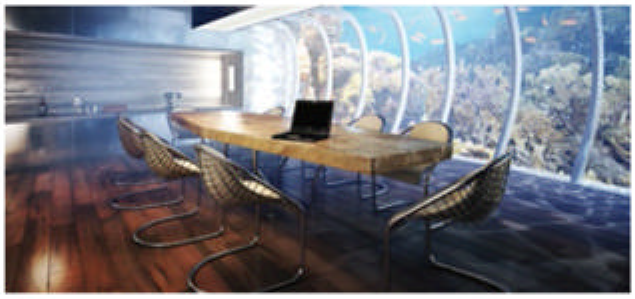
**Transplanting corals**
When small fragments of living coral are added, they quickly multiply and spread across the structure's surface.

**Steel skeleton**
A low-voltage electrical supply is connected to one end of a steel frame, bolted to the seabed.

**Renewable energy**
The electricity supply can come from a solar array or wind turbine to avoid the problems of offshore cabling.

**Mineral accretion**
The electrical charge attracts mineral ions from the water, which precipitate onto the frame as limestone and brucite rock.

We may soon literally sleep with the fishes in marine H$_2$OMEs currently under development



The 21 suites of the Water Discus Hotel will be located 10m (33ft) below the surface, surrounded by coral reefs

### 1968
**Helgoland**
The first underwater habitat built for cold waters, Helgoland is a 14 x 7m (46 x 23ft) cylinder that operates in the North and Baltic seas.

### 1969
**Tektite**
This 15m (49ft)-deep research habitat comprises two metal cylinders on a rectangular platform with a flexible tunnel connecting them.

### 1970
**Hydrolab**
Over 15 years, Hydrolab hosts 180 separate missions. Four scientists can live for weeks at a time in the 6m (20ft) cylinder (right).

### 1986
**Aquarius**
Still in use today, it weighs 73 tons and can be deployed in water up to 37m (120ft) deep. It has six bunks, a shower and a Wi-Fi connection.

### 2005
**Ithaa**
This restaurant in the Maldives (right) sits 5m (16.4ft) below the surface. Diners enjoy 180-degree panoramic views while they eat.

© Poseidon Undersea Resorts; Karine Rousseau Design Studio; Deep Ocean Technology; Conrad Hotels & Resorts; NASA; NOAA; Getty

# Construction of tunnels

## Discover the technology that blazes trails through solid rock

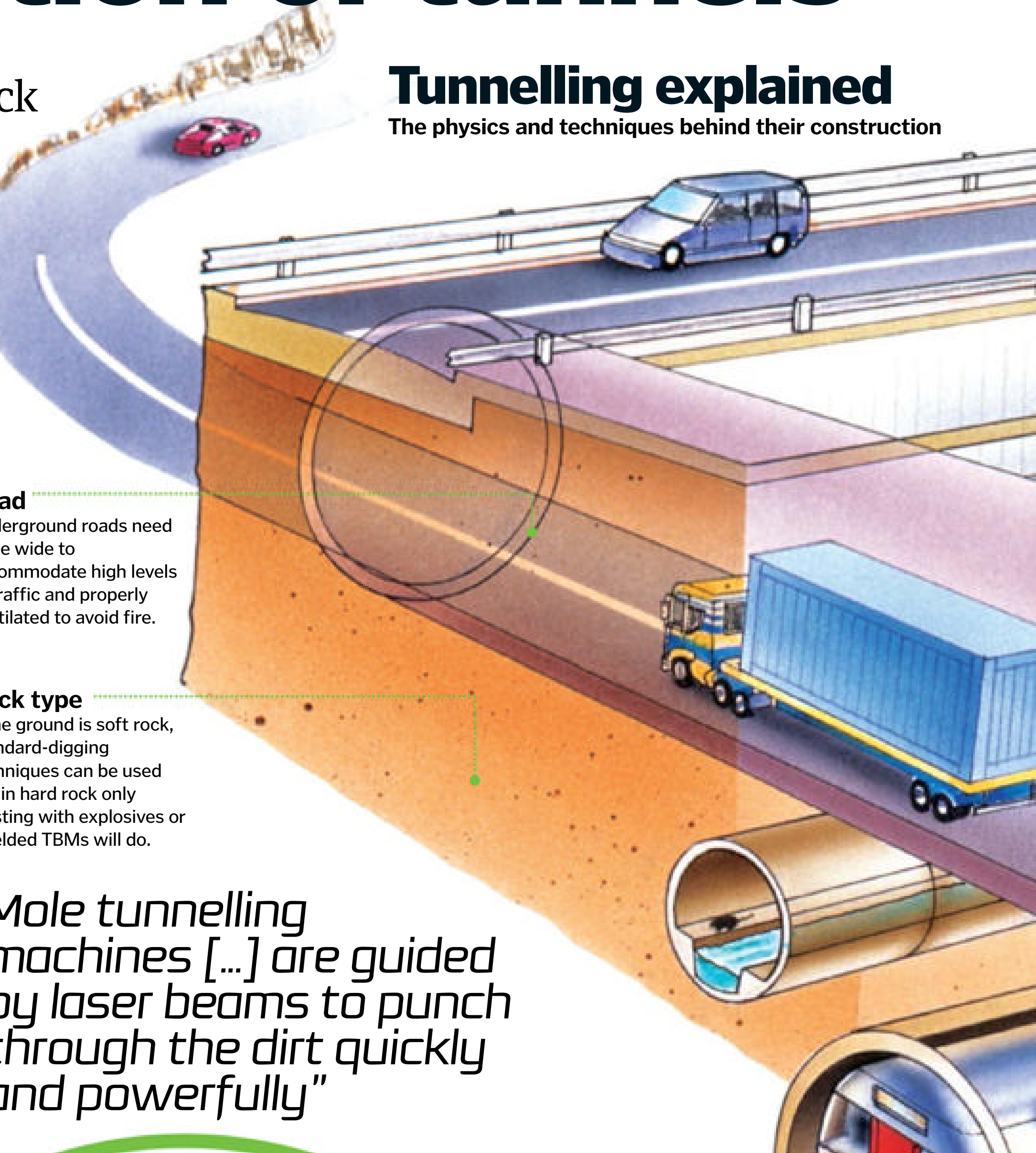
From mining to transport infrastructure and sewage control, tunnels are essential for an array of purposes. The longest in the world is the Delaware Aqueduct in the United States at an astonishing 137 kilometres (85.1 miles) long. The Seikan Tunnel, linking the Japanese islands of Honshu and Hokkaido, is the longest rail tunnel and spans a mighty 54 kilometres (33.4 miles). However, by 2016 it will be trumped by the Gotthard Base Tunnel (GBT) in Switzerland, which will be three kilometres (1.9 miles) longer.

To start a tunnelling project, you must first plan a geologic analysis of the area. By making a judgement on the rock and soil type, a construction's properties and dimensions can be adjusted accordingly. For example, you would use lighter materials and equipment on softer rock. An initial opening is made first, which is held up by rock bolts and a shotcrete lining to stop the structure from collapsing during construction. There must also be plenty of ventilation shafts to avoid any chance of suffocation, poisoning or heat exhaustion. Only then can the construction of a tunnel get under way in earnest.

Since 1954, large projects have used 'mole' tunnel boring machines that are guided by laser beams to punch through the dirt quickly and powerfully. A technique known as the immersed-tube method works by inserting prefabricated tunnels into a previously dug trench. This procedure has been found to be extremely effective, especially in underwater developments. In smaller constructions, hand tunnelling is still frequently used as it is much more cost effective than using a giant machine to carve pathways through rock.

## Tunnelling explained

**The physics and techniques behind their construction**

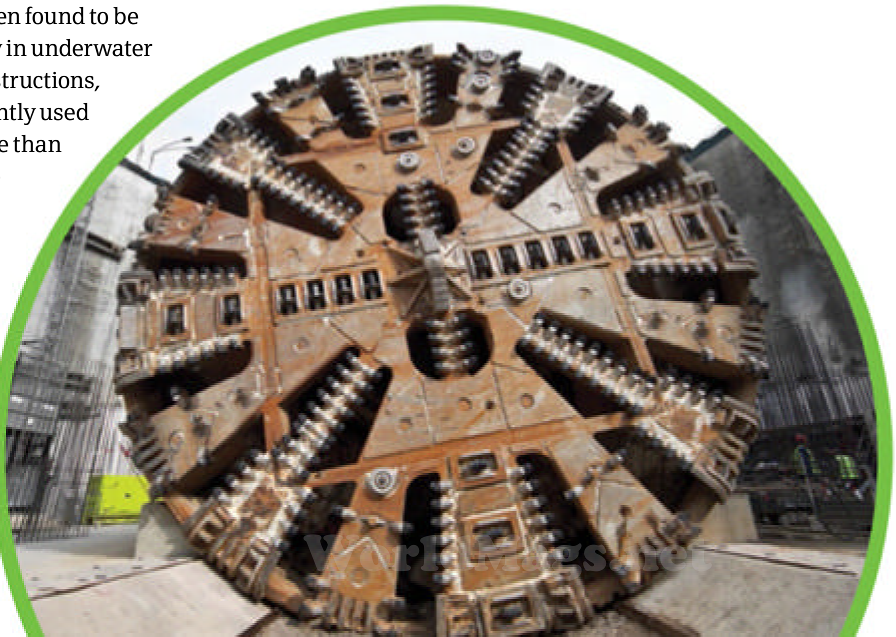


**Road**
Underground roads need to be wide to accommodate high levels of traffic and properly ventilated to avoid fire.

**Rock type**
If the ground is soft rock, standard-digging techniques can be used but in hard rock only blasting with explosives or shielded TBMs will do.

**Railway**
Tunnel boring machines (TBMs) construct underground railway tunnels by using a rotating cutter with a force equivalent to lifting over 2,900 London taxis.

> *"Mole tunnelling machines [...] are guided by laser beams to punch through the dirt quickly and powerfully"*



**RIGHT** A tunnel-boring machine head like the one used on mole tunnelling machines

# 154km

## THE REAL LONGEST TUNNEL?

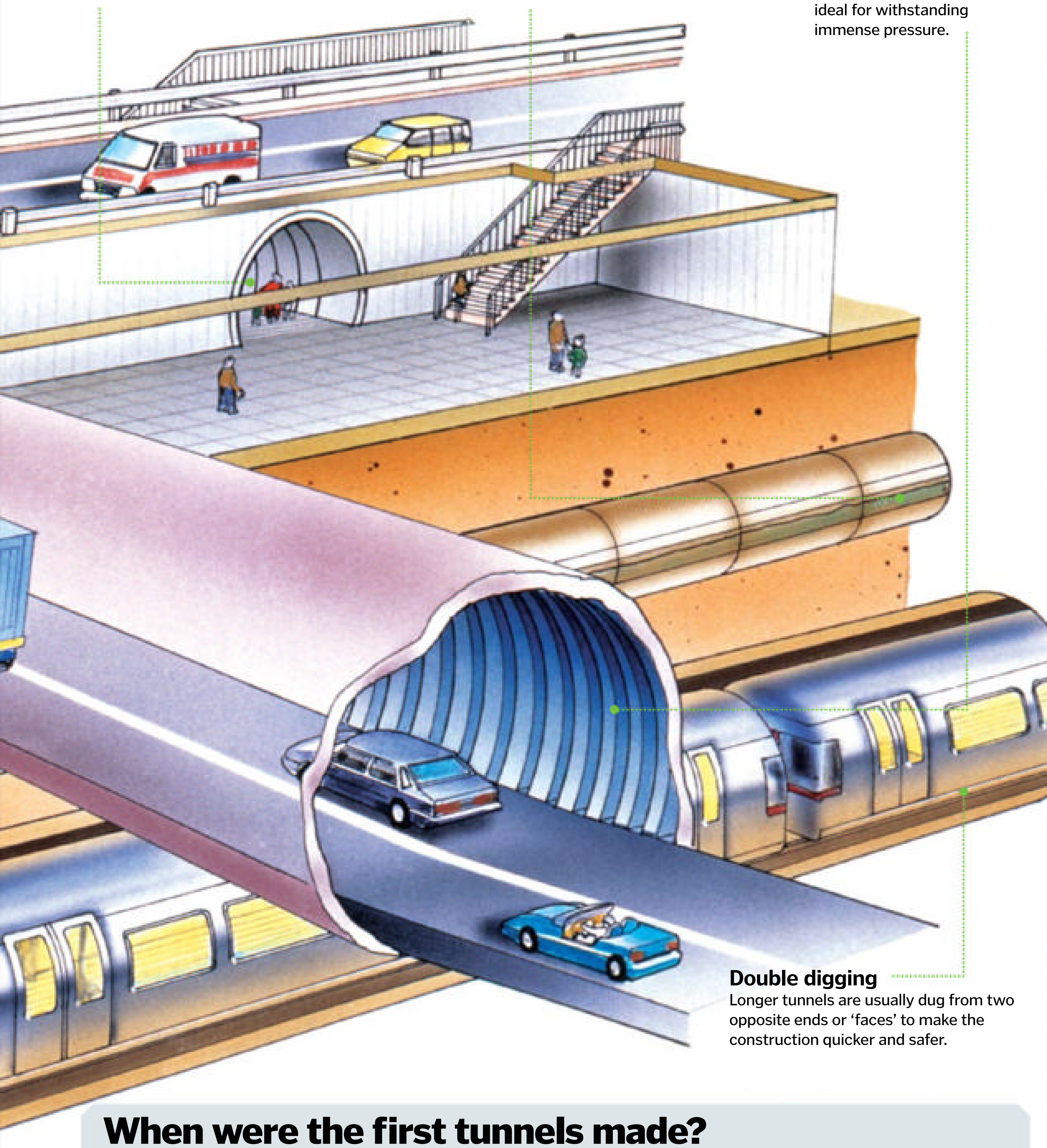
The Thirlmere Aqueduct was constructed in Northwest England in 1925 and would be the longest tunnel in the world if its length was continuous and didn't have gaps in it.

**DID YOU KNOW?** *The TBM 'Bertha' is named after Bertha Knight Landes, the first female mayor of a major US city*

**Pedestrian**
Underpasses are designed to relieve congestion on the streets and can be made quickly as they are only constructed marginally below ground.

**Wastewater**
Cities use huge sewage systems made of tough interlocking concrete segments to ferry waste to out-of-town treatment farms.

**Inverts and crowns**
The bottom half of a tunnel is called the invert while the topside is a crown. An arch is an incredibly strong structure ideal for withstanding immense pressure.



**Double digging**
Longer tunnels are usually dug from two opposite ends or 'faces' to make the construction quicker and safer.

**23 METRES WIDE**
The Yerba Buena Island tunnel is the largest single-bore tunnel

**15 MILES**
Longest road tunnel in the world is the Lærdal Tunnel

**38 KILOMETRES UNDERWATER**
The Channel Tunnel has the longest undersea portion of any tunnel

**54 KILOMETRES**
The longest rail tunnel is the Seikan Tunnel

**4.9km**
The Fenghuo Mount Tunnel is the highest tunnel on Earth

**600**
tunnels in the Netherlands have been built to help the local endangered animals

**240 METRES BELOW SEA LEVEL**
The Seikan Tunnel is also the deepest rail tunnel

**175 METRES UNDERGROUND**
The Large Hadron Collider in Switzerland

**30 MILLION TONS**
Rock that has been blasted out of the Alps to make the St Gotthard Base Tunnel.

## When were the first tunnels made?

As civilizations prospered and grew, natural obstacles like mountain ranges had to be mined through to gain access to other valleys as well as locating natural resources and precious gems. The first tunnels were built in Ancient Egypt and Babylon and were used primarily for irrigation. Constructions became more ambitious in the Roman era with the Cloaca Maxima in Rome an example of improved engineering. The first railroad tunnel built for US railroads was the Staple Bend Tunnel on the Allegheny Portage Railroad in 1833. Nearly 11,400 cubic metres (402,300 cubic feet) of rock were blasted out to construct it. In the 19th century, tunnels were built using a tunnelling shield first created by Marc Brunel (father of the famous Isambard) in 1825 and improved upon by Peter Barlow and James Greathead in the 1880s. This system would protect miners under a reinforced hood that shielded them from water and rubble. Since the start of the 20th century, huge projects, including many in the Alps such as the Mont Blanc and Arlberg Tunnels, have helped to develop new ventilation and water management techniques.

© Thinkstock

# Under the Wimbledon roof

## The technology that means rain no longer stops play

Tennis is a sport that requires good weather, so it's surprising that one of its premier competitions has been held in rainy England since 1877. So after 132 years and countless rain delays, a roof was built on Wimbledon's Centre Court for the 2009 Championships. The primary function is to keep water off of Centre Court so games can continue when a downpour begins, but it also means games can continue after dark.

The roof spans 5,200 square metres (56,000 square feet) and is made up of a translucent membrane held up by ten steel trusses, each weighing around 70 tons.

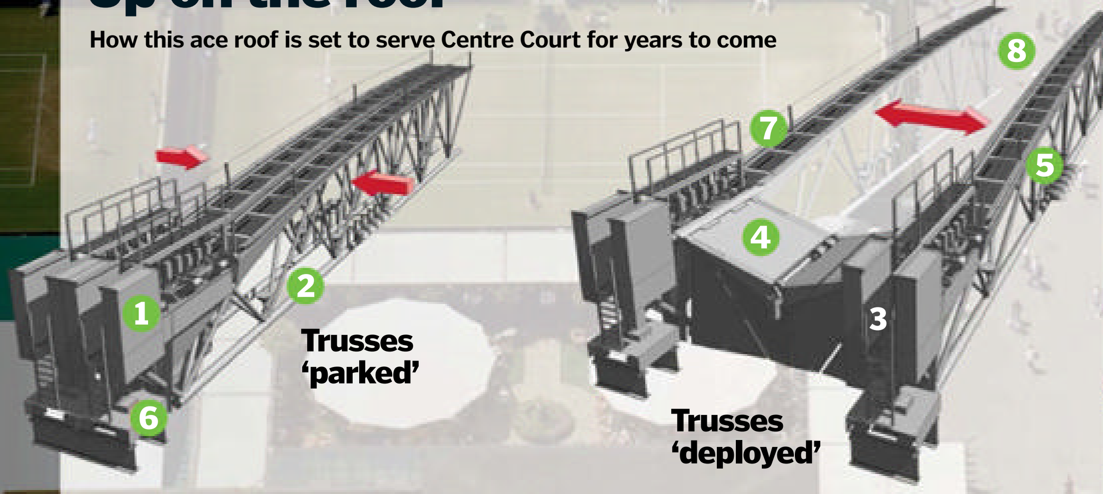
John Biggin was project manager of the build and explains how the roof closes: "The whole system is electrically powered. Actuators push on V-shaped arms, which flatten out, pushing each truss apart. These run on bogies, spreading along rails until the roof is covered."

It only takes around eight minutes to close but the lights and air management system take up to half an hour to get working. The roof cuts out 60 per cent of the natural light so 120 specialist sports lights are used to provide the correct lighting levels required for both the match and the television broadcasts. The air-conditioning system regulates the temperature and removes moisture from inside the stadium so conditions are as similar to a roofless atmosphere as possible.

"The main challenge was the design," says Biggin. "We used the concertina because of space restrictions but we built a model at Sheffield so we knew it worked. It's the only one in the world." The Wimbledon roof has revolutionised one of the world's most famous sporting events by allowing matches to go on long after dark or while the traditional rain is lashing down all around.

## Up on the roof

**How this ace roof is set to serve Centre Court for years to come**



**1 Control gear boxes** These gear boxes operate the actuators.

**2 Trusses** Each of the ten steel trusses that span the court weighs 70 tons.

**3 Actuators** Electronic actuators push down on the arms between the trusses.

**4 Arms** As the arms are pushed, they spread the trusses apart, closing the roof.

**5 Lights** 120 sports lights are carefully arranged so the court is evenly lit.

**6 Bogies** The trusses run on these wheeled trolleys that run along a rail.

**7 Locking arms** Arms across the top of the roof lock in place to withstand wind and rain.

**8 Time** It takes between eight and ten minutes for the roof to close.

## THE STATS

GAME, SET, STATS

TOTAL WEIGHT
3,000 tons

WIDTH
77m

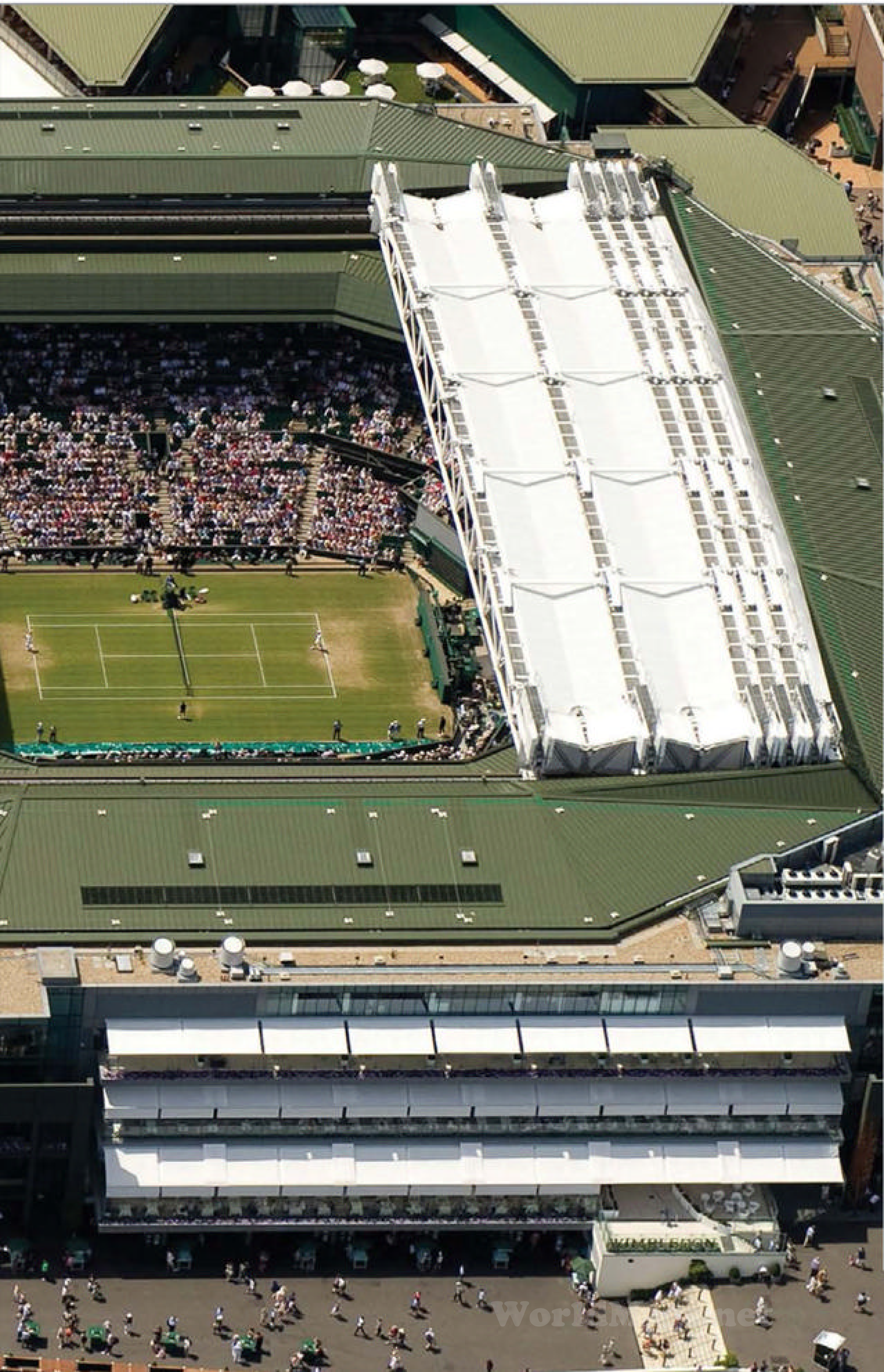
LENGTH
65m

BUILT
2009

CLOSING TIME
8-10 mins

LIGHTS
120

**DID YOU KNOW?** *Amelie Mauresmo and Dinara Safina were the first players to play under the new Centre Court roof*



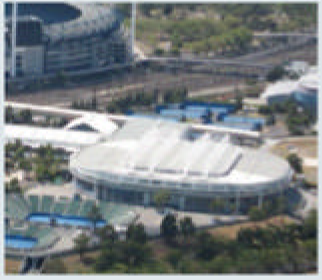
## Incredible retractable roofs

### Rogers Centre, Toronto

When it was finished in 1989, the Rogers Centre became the first sports stadium in the world to have a retractable roof. Constructed from four huge steel panels, the 11,000-ton roof slides away in just 20 minutes.

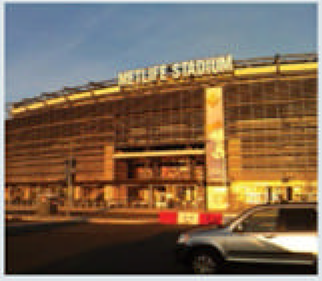
### Rod Laver Arena, Melbourne

The venue for the Australian Open final has a retractable roof, vital for a venue that experiences scorching temperatures and lashing rain. The rust-proof roof takes 20 minutes to shut, rolling over the court on arched trusses at 1.3 metres (4.3 feet) per minute.



### New Atlanta Stadium, Atlanta

The proposed new home of NFL team Atlanta Falcons will sit beneath a mind-boggling roof. It will close like a camera lens, its eight sections swooping dramatically shut.



© Thinkstock; Alamy; Populous

# Inflatable concert halls

Listen out for the world's first pop-up concert hall

Tuba players around the world had better take a deep breath because they might soon have to blow up their own concert halls if this incredible project is anything to go by.

Artist and sculptor Anish Kapoor and architect Arata Isozaki teamed up to create this amazing 18-metre (59-foot) high and 36-metre (118-foot) long by 29 metre (95 feet) wide structure, which held a series of concerts at Matsushima, Japan. The project came about in order to bring a bit of joy back to the group of islands on Japan's northeastern coastline, which was decimated by a tsunami after the catastrophic earthquake in 2011.

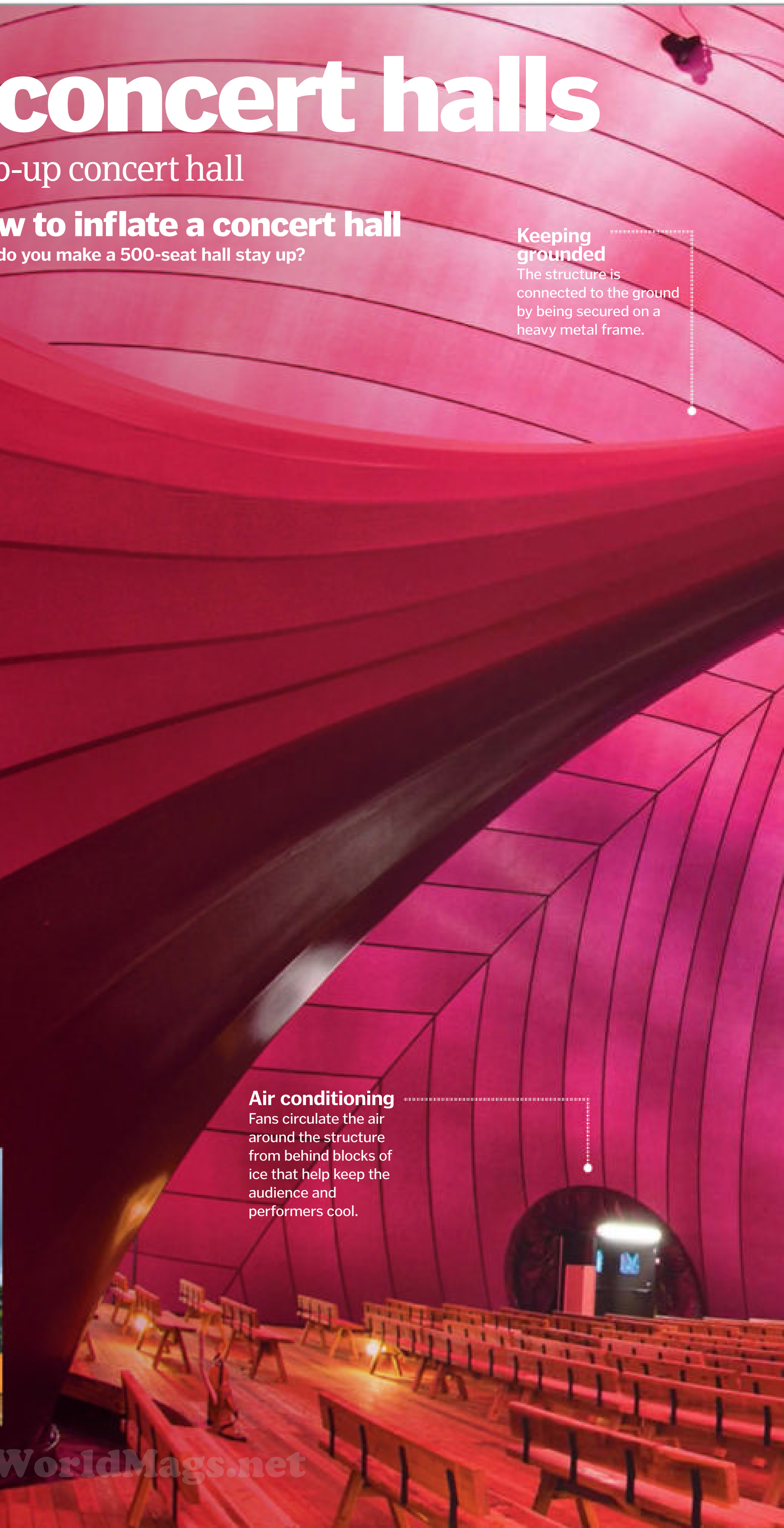
It's made of a stretchy plastic membrane that can be inflated by pumping gallons of air into it and deflated quickly. It can fit 500 audience members inside its stylish walls, as well as the orchestra. It took two years of planning and uses key parts of the local landscape in its design, such as cedar trees that were destroyed in the disaster being used for seating.

The air-conditioning system is cooled by giant blocks of ice and the revolving doors have been specially created in Germany with completely airtight seals, so no air is able to escape from inside the dome. Huge fans keep the air pushing against the PVC-coated membrane, so the entire structure doesn't collapse around the spectators.

This amazing design can fully inflate in just two hours despite its huge size. Although unlikely to replace Sydney or Moscow as the world's most iconic opera houses, it could make a massive impact with pop-up buildings in disaster areas based on the same principles.

## How to inflate a concert hall

**How do you make a 500-seat hall stay up?**



**Keeping grounded**
The structure is connected to the ground by being secured on a heavy metal frame.

**Air conditioning**
Fans circulate the air around the structure from behind blocks of ice that help keep the audience and performers cool.

An inflatable hall in standby mode

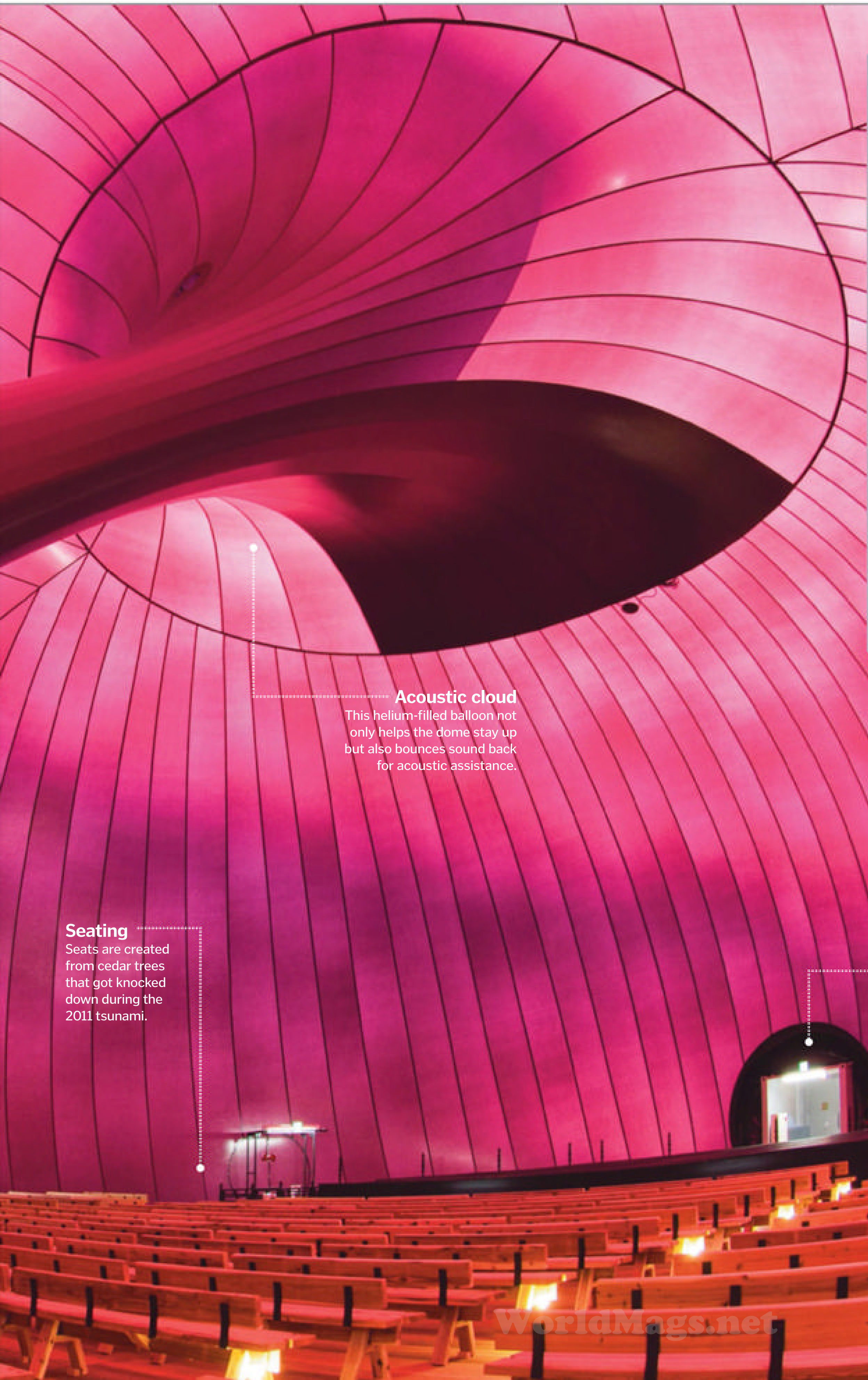
## Concert hall concepts

The Sydney Opera House is one of the most instantly recognisable buildings in the world. It took 16 years to build and beat competition from 232 other entries. It cost over AU$100m to build and its roof sections weigh 15 tons.

No less striking, the Bolshoi Theatre in Moscow is a symbol of Russian architecture and resilience. Burned down twice before being rebuilt into the huge structure seen today in only three years, it can seat 1,740 people.

Opened in 1778, Milan's La Scala is believed to be the finest opera house in Europe. The very first opera put on was *Europa Riconosciuta*. It has 2,800 seats, with the very top rows called the loggione – where all the fiercest critics choose to stand.

Possibly the most iconic music hall in the world is in Sydney



**Acoustic cloud**
This helium-filled balloon not only helps the dome stay up but also bounces sound back for acoustic assistance.

**Material**
A PVC-coated polyester fabric is used, as it has high tensile strength but can also be deflated easily then packed away tightly.

**Seating**
Seats are created from cedar trees that got knocked down during the 2011 tsunami.

**Entrance**
At the entrance is a tightly sealed revolving door that doesn't let air out.

© Lucerne Festival ARK NOVA

# CONTROLLING THE WEATHER

## DISCOVER HOW WE MAKE RAIN AND THE AMBITIOUS PLANS BEING HATCHED TO TACKLE CLIMATE CHANGE

Superhero Storm in the *X-Men* comics can conjure rain, end droughts and create hurricanes with the power of her mind. Now, scientists and meteorological technology are opening more and more opportunities for us mere mortals to manipulate weather and Earth's climate.

In 2009, Chinese meteorologists from the Beijing Weather Modification Office claimed to be responsible for the city's earliest snowfall since 1987. Around 16 million tons of snow reportedly fell over drought-afflicted northern China after workers fired rockets carrying pellets of silver iodide into heavy clouds.

The rockets were cloud seeding, a process invented in the late-Forties. Supporters claim it can reduce hail damage, increase rainfall and disperse fog among other things. There are cloud-seeding projects in at least 20 countries worldwide, from Israel to Australia; in 2003, in the US alone, ten states were conducting at least 66 cloud-seeding programmes. In China, around 32,000-35,000 people are employed in the weather modification industry.

The big question in cloud seeding is: how effective is it? A 2003 US National Academies report concluded there was no concrete scientific proof it worked. According to Professor Michael Garstang from the University of Virginia, who chaired the report, the situation hasn't changed much since; there remains "a lack of definitive evidence," he says.

Even cloud-seeding supporters admit it doesn't currently lead to a huge rise in rain and snowfall. "It doesn't increase precipitation by 50 per cent in most cases," says Bruce Boe from Weather Modification Inc, a private weather control company based in North Dakota, USA.

US enthusiasm for weather modification research waned in the late-20th century, with funding falling to less than five per cent of its Seventies peak. But there are signs of fresh interest in the field. The US National Science Foundation (NSF) is funding a cloud-seeding project in the Wyoming mountains, operated by Weather Modification Inc. New technology, such as advanced computer models and radar instruments that can see inside clouds is driving the resurgence of interest, says Boe: "We're bringing a lot of new tools to bear on the question. These tools weren't available before and they're starting to bear fruit."

The Wyoming project, launched in 2005, uses aircraft-mounted radar and ground-based

## 5 TOP FACTS
### MYTHS BUSTED

**Geoengineering is ready**

**1** Today's geoengineering ideas are untested or small-scale experiments. Cooling Earth by one degree Celsius would require a minimum five years of military-scale effort.

**One tech is enough**

**2** No single 'magic technology' can cool the Earth. Future geoengineers might use many fixes, like reflective buildings, a space-based deflector and encouraging reforestation.

**It solves climate change**

**3** Geoengineering doesn't stop greenhouse gas emissions – the root cause of man-made climate change. It's a 'plaster', pausing harmful warming to give us time to cut emissions.

**We can't create rain**

**4** There's emerging evidence that cloud seeding *can* make rain. An Australian project in 2005-2009 found that rainfall increased in suitable clouds by an average 14 per cent.

**It's all a conspiracy**

**5** There's no scientific evidence behind claims that HAARP, a US facility studying Earth's ionosphere, is a secret conspiracy for creating hurricanes as weapons.

**DID YOU KNOW?** *A global survey in 2010 found 72 per cent of us supported research into reflecting sunlight to cool the planet*

instruments. It tests the effectiveness of seeding winter orographic clouds – which are cold clouds formed when air rises over mountains – with silver iodide.

"In the mountains of the American West, these types of storms are the main target for cloud seeding. Often the clouds are not efficient at generating snow, so cloud seeding is used to enhance snow production," says Dan Breed from the US National Center for Atmospheric Research (NCAR), who is evaluating the project.

Another aim of the experiment is to increase snowfall by perhaps ten per cent a year, building up the winter snowpack so it's available for use. The extra water running off the mountains each spring would be worth an estimated £1.5-3 million ($2.4-$4.9 million).

Cloud seeding affects the weather in a local region, but there are other technologies being devised to alter climate on a much bigger scale. Space mirrors and giant floating hosepipes might sound far-fetched, but they're two proposals for geoengineering. Geoengineering is deliberate global modification of Earth's climate to counter man-made climate change.

Geoengineering may sound impossible, but serious scientists are investigating how it might cool down the planet. In the last few years, billionaire Bill Gates reportedly donated £2.8 million ($4.5 million) to geoengineering research, and the UN IPCC report, a summary of what most scientists agree we know about climate change, mentioned geoengineering for the first time this year.

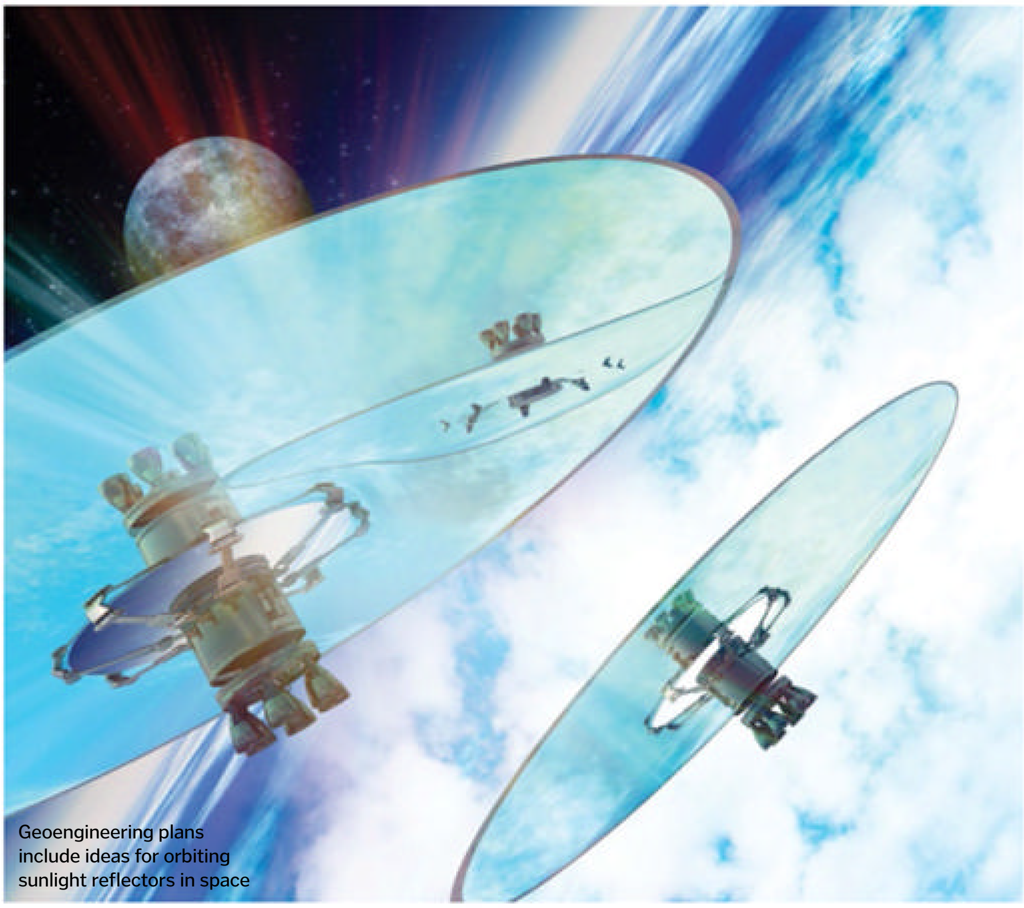
Geoengineering is essentially 'Plan B' in case we reduce greenhouse gas emissions 'too little, too late' to avoid dangerous climate change, argues a 2009 report by the UK's Royal Society. A temperature rise of just two degrees Celsius (3.6 degrees Fahrenheit) could melt the Greenland ice sheet and cause a long-term sea level rise of seven metres (23 feet). That's enough water to submerge both London and Los Angeles.

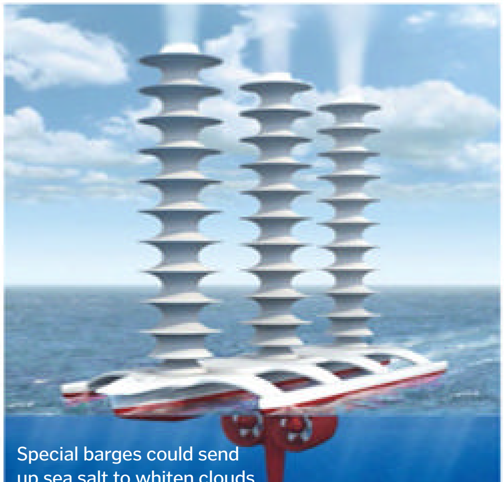
To avoid this wide-scale warming, we'd need to cut global carbon dioxide emissions by 50 per cent of 1990 levels by 2050, according to the Royal Society. Yet emissions are still rising – by 1.4 per cent during 2012. Even if we cut carbon emissions today, temperatures will continue rising for decades. The climate system is like an oil tanker – ie slow to turn around.

Dr Hugh Hunt is an engineer from Cambridge University working on SPICE (Stratospheric Particle Injection for Climate Engineering) – a UK government-funded geoengineering research project: "We don't know what the scale of unabated climate change will be," he says. "You've got to think in advance what emergency measures you might need, and then hope you won't need them."

There are two types of geoengineering. Solar radiation management (SRM) cools the Earth by reflecting the Sun's heat back into space, while carbon dioxide removal (CDR) scrubs $CO_2$ – the primary greenhouse gas causing man-made climate change – from the atmosphere.

Examples of SRM include space mirrors, injecting sulphate aerosols into the atmosphere through giant hosepipes and painting urban roofs white. One idea uses cloud seeding to make clouds more reflective. Fleets of unmanned 3,000-ton barges could sail the oceans, spraying clouds with saltwater. Salt particles should create more water droplets in the clouds, whitening them. Proposals for CDR include fertilising tiny marine plants with iron, growing new forests or fast-growing crops and burying charcoal, all of which lock up $CO_2$ and remove it from the air. Most geoengineering proposals remain in the lab at this stage. "We can do very little right now because the


Geoengineering plans include ideas for orbiting sunlight reflectors in space

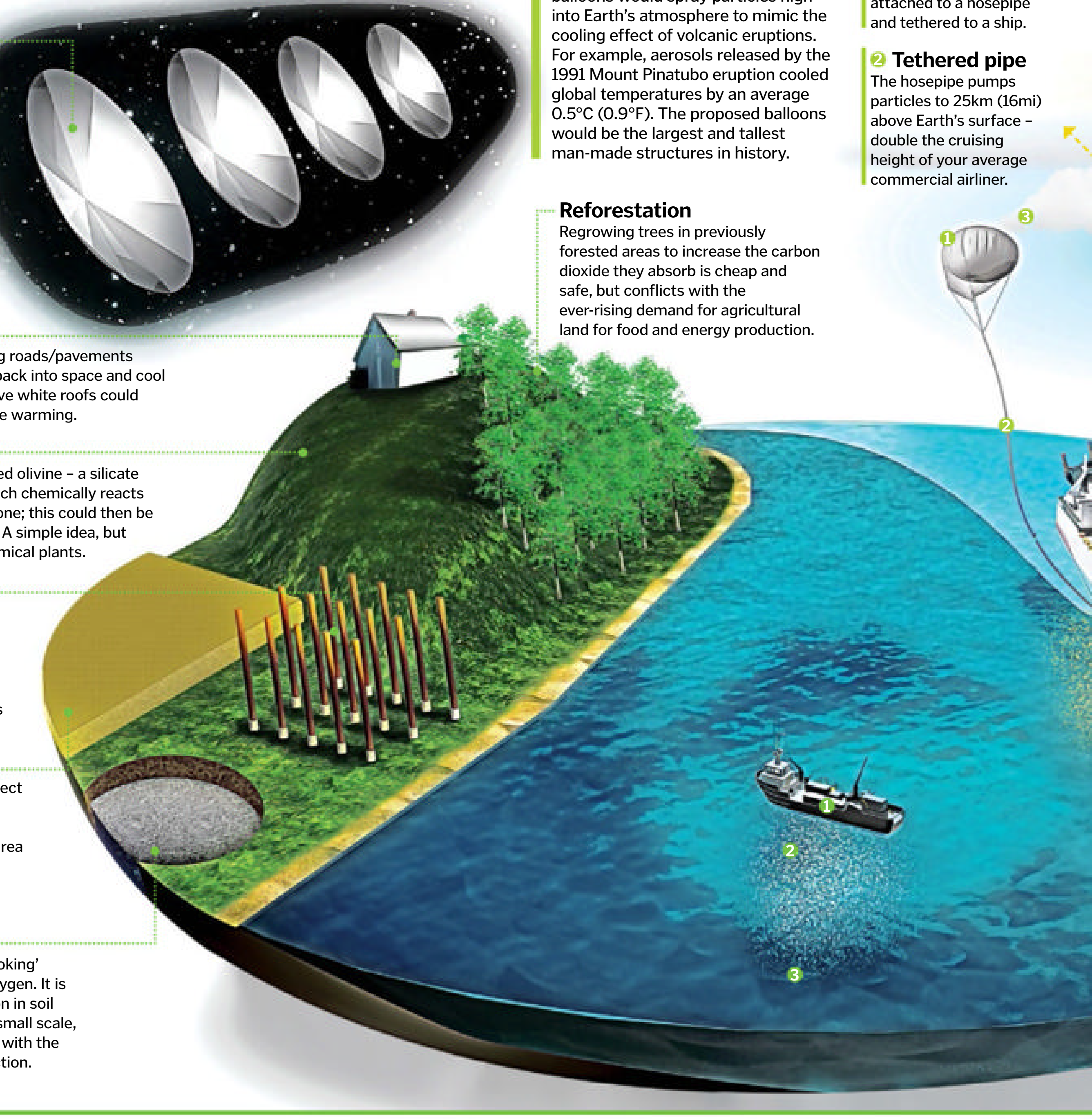

Special barges could send up sea salt to whiten clouds and help reflect sunlight

New technology has led to a resurgence in cloud-seeding projects

© John MacNeill Illustration; SPL; Weather Modification Inc./Bruce Boe, Christopher Grillot; Peters & Zabransky

# Weather-changing tech in action

**Discover the machines and techniques capable of adapting Earth's climate**



### Space mirrors

A giant sunshade made of tiny mirrors could be put into orbit to cool the Earth. Taking decades and trillions of dollars to deploy, its effect on our weather is unknown and it would not stop the oceans acidifying.

### Reflective buildings

Painting roofs white and brightening roads/pavements should help bounce the Sun's heat back into space and cool the Earth, but some scientists believe white roofs could reduce cloud formation and increase warming.

### Enhanced weathering

This would involve spreading crushed olivine – a silicate mineral – over agricultural land, which chemically reacts with $CO_2$ to produce alkaline limestone; this could then be used in the ocean to reduce acidity. A simple idea, but would require huge mining and chemical plants.

### Artificial trees

These towering machines would scrub carbon dioxide from the air, turning it into liquid that can be stored in porous rocks beneath the oceans. Millions of artificial trees would be needed and the $CO_2$ needs storing for millions of years.

### Reflective crops

Certain crops, shrubs and grass reflect more sunlight back into space than others. This would be cheap to implement, but needs a huge land area and has unknown effects on food prices, plant growth, disease and drought resistance.

### Biochar

Biochar is charcoal produced by 'cooking' plants or manure with little or no oxygen. It is decay-resistant and can store carbon in soil for thousands of years. Useful on a small scale, but growing biochar crops conflicts with the demand for food and biofuel production.

## Volcano balloons

Hosepipes attached to giant helium balloons would spray particles high into Earth's atmosphere to mimic the cooling effect of volcanic eruptions. For example, aerosols released by the 1991 Mount Pinatubo eruption cooled global temperatures by an average 0.5°C (0.9°F). The proposed balloons would be the largest and tallest man-made structures in history.

### ❶ Helium balloon

A helium balloon the size of a football stadium is attached to a hosepipe and tethered to a ship.

### ❷ Tethered pipe

The hosepipe pumps particles to 25km (16mi) above Earth's surface – double the cruising height of your average commercial airliner.

### Reforestation

Regrowing trees in previously forested areas to increase the carbon dioxide they absorb is cheap and safe, but conflicts with the ever-rising demand for agricultural land for food and energy production.

technology hasn't been developed to intervene on a planetary scale," notes Andy Parker.

Still, there are a few examples of outdoor field tests. The SPICE project included a plan, later abandoned, to pump water one kilometre (0.6 miles) vertically through a pipe attached to a helium balloon. Its aim was to test the feasibility of squirting sulphate aerosols through a giant hosepipe 20 kilometres (12 miles) above the ground. "We don't know if it's technically possible," continues Dr Hunt. "No one has built a 20-kilometre (12-mile) pipe that goes vertically upwards." Among his unanswered questions are, firstly, can we build and launch a balloon big enough, and secondly, can we build a pipe strong enough?

Other geoengineering proposals rely on pre-existing technology. Fertilising oceans with iron, for example, has already happened on a small scale although not necessarily legally. It needs lots of tanker ships, chemical plants and iron. "There's nothing technically difficult about that," says Professor Andy Ridgwell from Bristol University.

It would take hundreds of years to see results from iron fertilisation and other CDR technologies though. They rely on slow natural processes, such as fertilising tiny marine plants that transport carbon into the deep ocean when they die. "You can't suddenly pull loads of

## KEY DATES
### MAN-MADE WEATHER

**1891**
Rainmaker Robert Dyrenforth tries proving noise causes downpours by exploding dynamite kites over Texas.

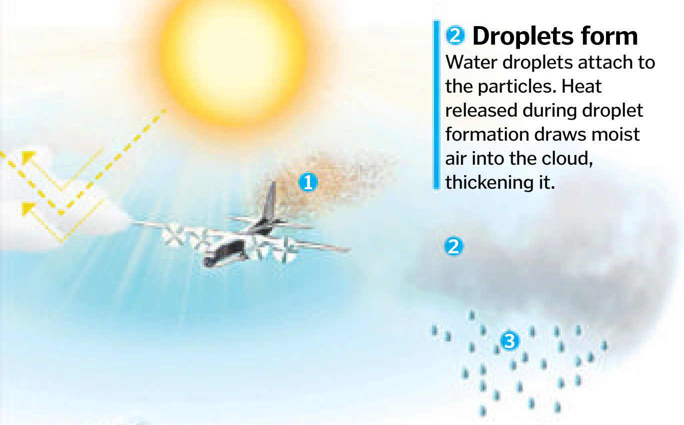
**1946**
Vincent Schaefer performs the first cloud-seeding experiments, dropping dry ice pellets into clouds.

**1952**
34 die in a flood in Lynmouth, England. The UK cloud-seeding Operation Cumulus is blamed.

**1967**
Operation Popeye, a secret US cloud-seeding project, seeks to deluge enemy troops in Vietnam.

**2008**
The Chinese government tries to prevent rain at the 2008 Beijing Olympics by launching 1,104 rockets.

**DID YOU KNOW?** *Global temperatures could rise by more than 1°C by the end of this century, even if we reduce carbon emissions*



**③ Spray of particles**
The hosepipe squirts the particles into the stratosphere, scattering solar radiation back into space.

**① Clouds seeded**
Silver iodide or salt is sprayed into clouds from a plane, with a rocket or from a floating barge.

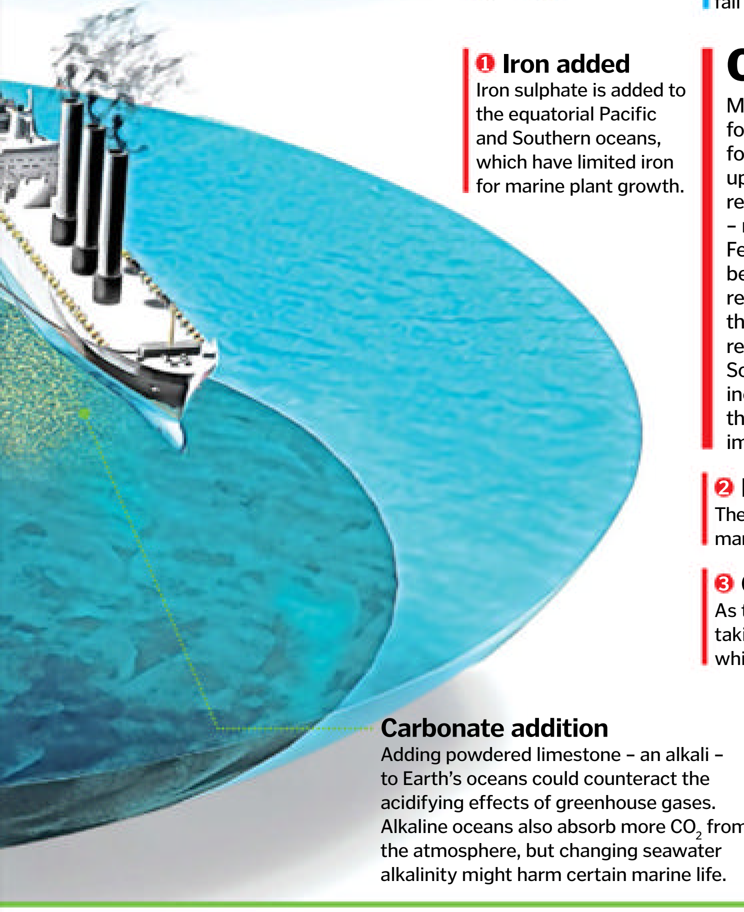
**② Droplets form**
Water droplets attach to the particles. Heat released during droplet formation draws moist air into the cloud, thickening it.

## Cloud seeding

Cloud seeding is a technique for man-made rainmaking already used around the world to varying degrees of success. Rainfall naturally occurs when water droplets attach to sand, dust or salt particles. Cloud seeding squirts extra particles into clouds to spawn new raindrops. Salt is used in warm tropical clouds, while silver iodide is added to cold clouds to create extra ice crystals.

Some scientists believe cloud seeding can brighten clouds to counteract climate warming too. The extra particles make the clouds denser, whiter and more reflective, deflecting more sunlight back into space.

**③ Rain falls**
The droplets or ice crystals collide, growing bigger and heavier until eventually they fall as precipitation.



**① Iron added**
Iron sulphate is added to the equatorial Pacific and Southern oceans, which have limited iron for marine plant growth.

## Ocean fertilisation

Marine plant life is at the core of the ocean food chain. The plants are a source of food for other marine life, and happen to take up and bind carbon dioxide as well. They rely on the availability of nutrients to grow – most commonly nitrogen or iron. Fertilising the oceans with iron sulphate is believed to increase their growth and reproduction, which would in turn increase the amount of carbon dioxide they take up, reducing the effect of carbon emissions. Some scientists also believe that the increased marine plant life may increase the number of fish in the sea, in turn improving our food supply.

**② Microalgae bloom**
The rich iron supply creates vast blooms of tiny marine plants, which take up $CO_2$ as they grow.

**③ Carbon locked away**
As the plants die, some fall to the ocean floor, taking locked-up carbon dioxide with them which becomes buried as sedimentary rock.

**Carbonate addition**
Adding powdered limestone – an alkali – to Earth's oceans could counteract the acidifying effects of greenhouse gases. Alkaline oceans also absorb more $CO_2$ from the atmosphere, but changing seawater alkalinity might harm certain marine life.

## Can we stop a hurricane?

Hurricane Katrina in 2005 was arguably the worst natural disaster in American history, and many scientists believe hurricanes will only worsen with climate change.

So there's no shortage of ideas for stopping these devastating storms. In 2009, Bill Gates backed a proposal to halt hurricanes by towing tub-like barges into their path. These would cool the warm ocean waters fuelling the storm.

Most plans underestimate a hurricane's power though; according to the NOAA Hurricane Research Division, one storm can release the energy of 10,000 nuclear bombs. For example, to fight a hurricane with water-absorbent powder you'd need hundreds of planes to make sorties every one and a half hours.

Some therefore argue that it's cheaper and more practical to adapt to hurricanes by, for instance, building stronger houses.

## The risks of geoengineering

Geoengineering is controversial because it involves large-scale changes to Earth's climate. Critics discuss possible negative side effects, like that ocean fertilisation might cause toxic algal blooms, or that geoengineering gives industry and government excuses not to cut carbon emissions.

Geoengineering also raises issues of ethics. Cooling the climate with sulphate aerosols "is potentially cheap enough for single countries to do", says Professor Andy Ridgwell, Bristol University, but could impact other countries' climates as well.

Others fear 'rogue' geoengineers. For example, an American businessman dumped 100 tons of iron sulphate into the Pacific in July 2012 in an unauthorised ocean fertilisation scheme.

carbon dioxide out of the atmosphere with any of them," explains Professor Ridgwell. "They lend themselves to gradual mitigation."

Growing vast new forests or fast-growing crops competes with existing land uses, explains Dr Tim Lenton from Exeter University. The idea is to repeatedly harvest fast-growing crops like eucalyptus, which capture the carbon dioxide they use to grow. Crops growing on the best soils take up the most carbon, but you want to use those soils to grow food. "The plausibility problem is that you're in potential competition with other land uses in a world where dietary demands are rocketing."

Reflecting sunlight back into space with aerosols is the fastest geoengineering method. It mimics the rapid cooling effect of a large volcanic eruption. "Once you start blocking out some sunlight, temperatures drop quite quickly," explains Andy Parker. For example, in the two years following the eruption of Mount Pinatubo in the Philippines in 1991, global temperatures cooled by about 0.5 degrees Celsius (0.9 degrees Fahrenheit) on average.

So realistically how fast could we cool the planet? Dr Hunt concludes: "Let's suppose the Greenland ice sheet completely melts and we get a one-metre [3.2-foot] sea-level rise. It could be done in five years – if we've got time to think about it, 20-30 years from now."

© Weather Modification, Inc/Christopher Grillot/Bruce Boe; SPL; Peters & Zabransky; NASA

# How to build a mega-aquarium

## Dive inside one of the largest aquariums on Earth and discover how we replicate an ocean in a tank

Aquariums, and in particular the awe-inspiring tunnel oceanariums that allow you to walk through marine environments yet stay completely dry, are amazing feats of modern engineering.

First of all, the engineers have to ensure the glass is strong enough to hold back up to 42.8 million litres (11 million gallons) of water. And no, we haven't just plucked that number out of thin air; that's the capacity of the SEA Aquarium in Singapore (see main image).

The SEA's acrylic panel is 36 metres (118 feet) wide, 8.3 metres (27.2 feet) tall and over 70 centimetres (27.6 inches) thick to cope with the immense pressure generated by the huge volume of water. Behind this panel are all manner of marine creatures, from goliath groupers to giant manta rays.

Even after the tanks have been constructed, the water poured in and salinated and the various fish introduced to their respective homes, a lot of upkeep is required. As the tanks are far more contained than the endless oceans, cleaning up waste matter and uneaten food must take place regularly. This is done using one of three common filtration techniques. Mechanical filtration employs filters and pumps to remove waste, fractionation separates the water from particles that have dissolved in it, and finally there is ozone, which kills off harmful bacteria in the water, much like chlorine in swimming pools.

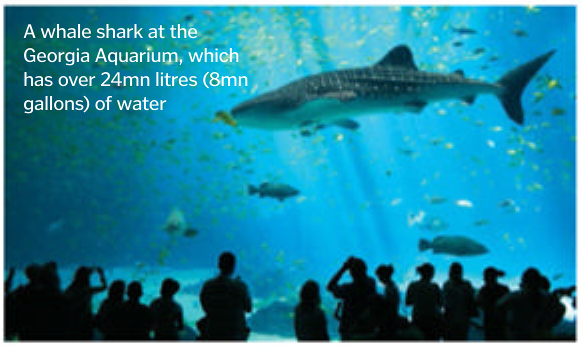
In order to keep the tanks clean for fish and viewers alike, sand filters and skimmers are also incorporated. The sand filters use pumps to blast the water through them and debris is caught by the fine grains, while the protein skimmers pass the water through a valve that injects air into it. This creates lots of tiny bubbles which any debris sticks to.

## Clear strength

Aquarium tanks have to meet rigorous safety standards. Often, all that stands between the public and millions of litres of water, sharks and other fish is a single sheet of acrylic. Acrylic has become the standard in aquariums due to its dual qualities of being extremely strong and transparent. The latter quality it, of course, shares with glass, but acrylic's strength really sets it apart.

Acrylic sheets are up to 17 times stronger than glass and have the added advantage of not becoming weakened by prolonged exposure to water. The high molecular weight of cast acrylic sheets makes cutting the panel much easier and the flexible nature of the plastic allows for curved viewing portals without compromising on structural integrity.

Although glass doesn't scratch as easily, acrylic is the way to go for a strong, durable, flexible and transparent material to best show off an aquarium's inhabitants.


A whale shark at the Georgia Aquarium, which has over 24mn litres (8mn gallons) of water

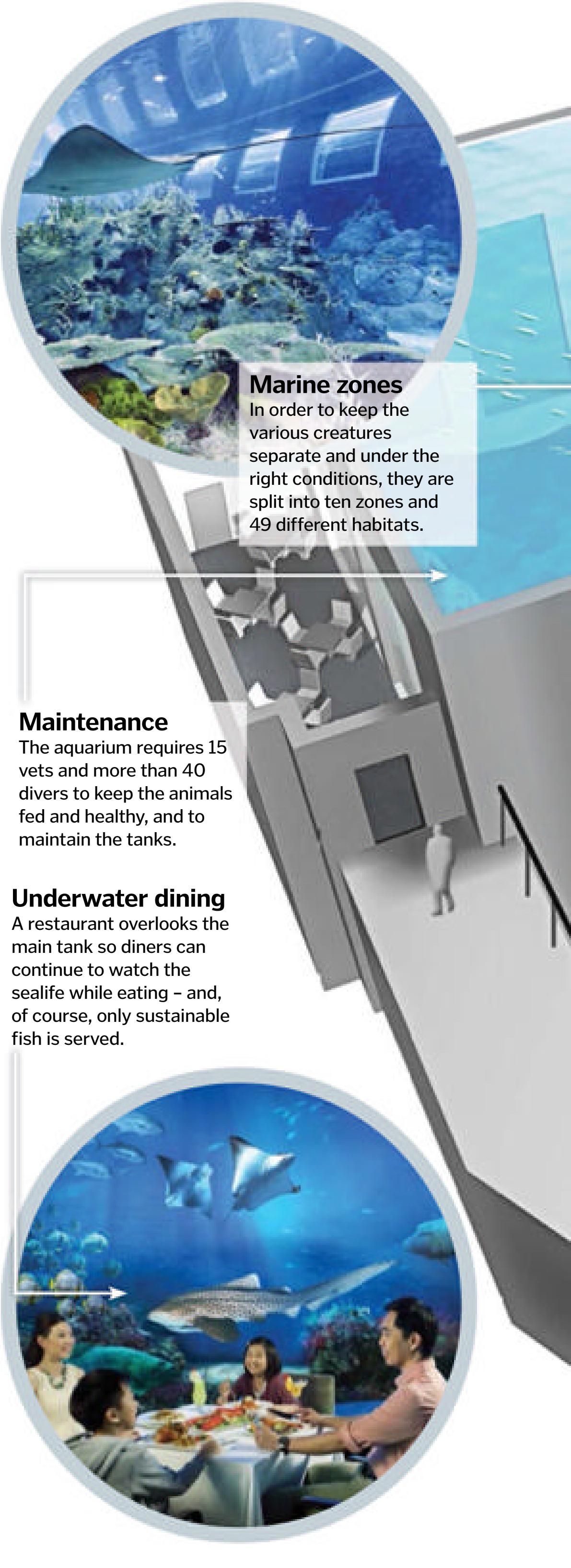
## Re-creating marine habitats

Every large aquarium has to deal with the challenge of meeting the needs of the diverse creatures it plays home to. Visitors want to see salt and freshwater fish, plus other creatures, so they have to replicate a variety of environmental conditions. The Ocean Voyager tank in the Georgia Aquarium, USA, poured 680,000 kilograms (1.5 million pounds) of sea salt into its 24-million-litre (6.3-million-gallon) tank. After this initial outlay though, the tank requires very little salt to keep it salinated.

Water temperature is also very important. Depending on the location and inhabitants, temperature varies wildly, so tanks are constantly checked and controlled by thermostats and heaters. For fish that live in deep water, dim lights are used so we can see them without upsetting their natural environment.

## Explore the SEA Aquarium

Take a tour of this supersized oceanarium in Singapore



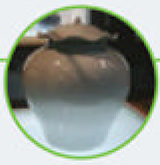
**Marine zones**
In order to keep the various creatures separate and under the right conditions, they are split into ten zones and 49 different habitats.

**Maintenance**
The aquarium requires 15 vets and more than 40 divers to keep the animals fed and healthy, and to maintain the tanks.

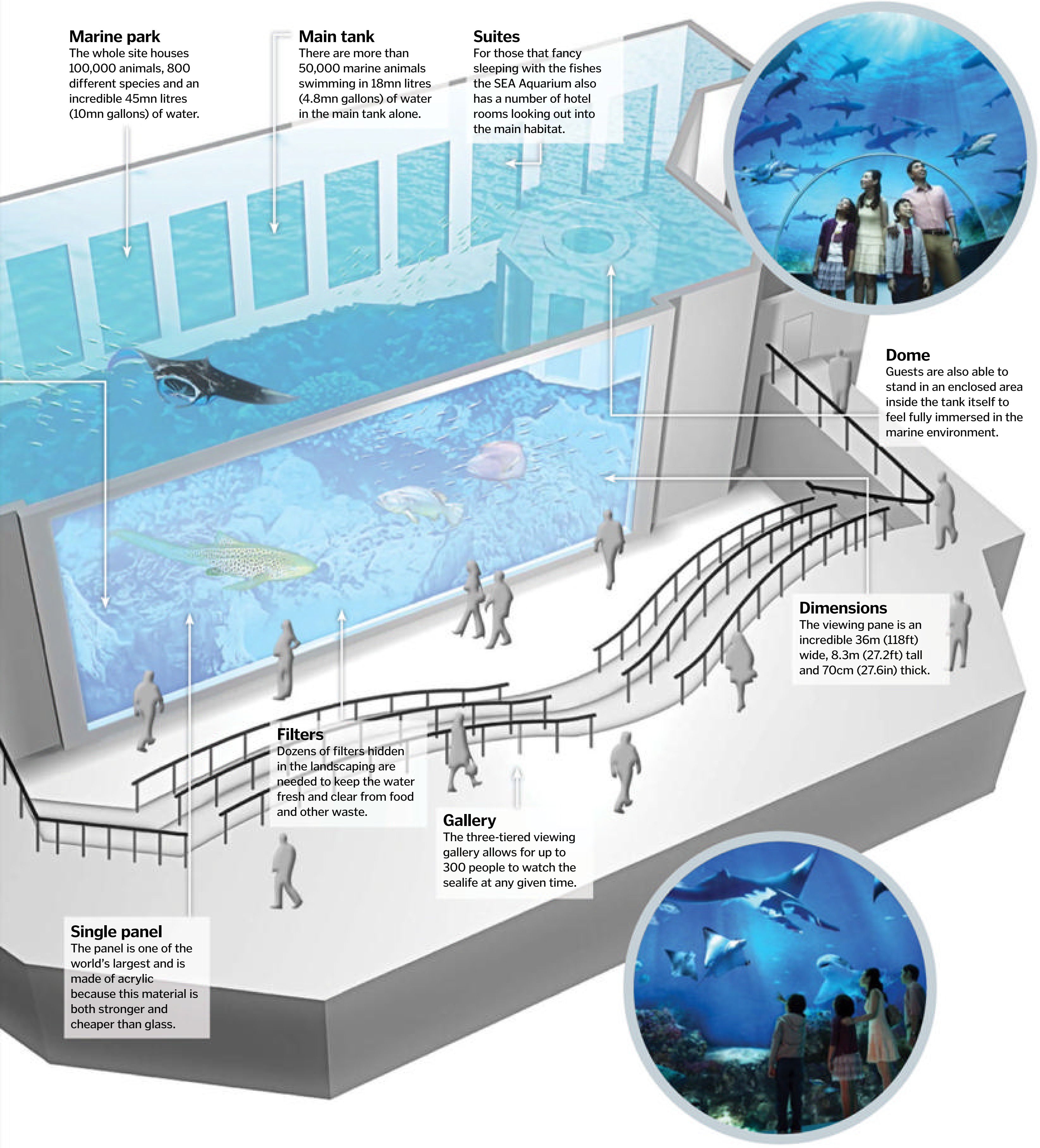
**Underwater dining**
A restaurant overlooks the main tank so diners can continue to watch the sealife while eating – and, of course, only sustainable fish is served.

## KEY DATES
### HISTORY OF AQUARIUMS

| 50 CE | 1369 | 1846 | 1853 | 1908 |
|---|---|---|---|---|
| The Romans are credited with the invention of the aquarium, the first a marble tank holding sea barbel. | Emperor Hongwu of China orders a porcelain company to begin making tubs to hold goldfish. | Anne Thynne is the first known person to create a balanced aquarium, filling it with coral and seaweed. | The first public aquarium opens in London Zoo, with Philip Henry Gosse (right) coining the word 'aquarium'. | The invention of the mechanical air pump heralds a revolution for aquariums as a home hobby. |



**DID YOU KNOW?** *The biggest acrylic panel is in the Hengqin Ocean Kingdom aquarium in China at 8.3 x 39.6m (27.2 x 129.9ft)*



**Marine park**
The whole site houses 100,000 animals, 800 different species and an incredible 45mn litres (10mn gallons) of water.

**Main tank**
There are more than 50,000 marine animals swimming in 18mn litres (4.8mn gallons) of water in the main tank alone.

**Suites**
For those that fancy sleeping with the fishes the SEA Aquarium also has a number of hotel rooms looking out into the main habitat.

**Dome**
Guests are also able to stand in an enclosed area inside the tank itself to feel fully immersed in the marine environment.

**Dimensions**
The viewing pane is an incredible 36m (118ft) wide, 8.3m (27.2ft) tall and 70cm (27.6in) thick.

**Filters**
Dozens of filters hidden in the landscaping are needed to keep the water fresh and clear from food and other waste.

**Gallery**
The three-tiered viewing gallery allows for up to 300 people to watch the sealife at any given time.

**Single panel**
The panel is one of the world's largest and is made of acrylic because this material is both stronger and cheaper than glass.

© Resorts World Sentosa; Peters & Zabransky

# Exploring a coal mine

Coal fuelled the Industrial Revolution and even today is responsible for 40 per cent of the world's electricity, but how is a colliery laid out?

There are two basic types of coal mines, also known as collieries. The first is the opencast surface mine, which consists of a coal seam covered by an overburden layer of soil and rock. Bulldozers clear the soil and explosives are used to break up the remaining overburden. Draglines and power shovels are then brought in to remove this material, followed by the extraction of the coal. After the mine is exhausted the topsoil is returned to landscape the area.

The second type, the underground mine (shown here), can access deeper seams of coal and is far more dangerous and challenging. Originally, the coal face was dug by pick and shovel, but as time went by, explosives were used to blast away at the coal seam.

Modern mines use machines that have tungsten bits that cut into the coal face. Longwall and room-and-pillar systems are the two main methods for extracting coal. The longwall method slices horizontally into the coal face and drops the mineral onto conveyer belts. The room-and-pillar method cuts a grid-like network of tunnels in the coal seam, leaving the remaining pillars to support the roof. The longwall method can be used to finish off the pillars that are left behind by the room-and-pillar technique.

## Fire in the hole!

Coal seams can catch fire and burn for decades or even centuries, either due to accidental causes such as gas explosions or natural causes when there is sufficient heat and ventilation to bring about self-combustion.

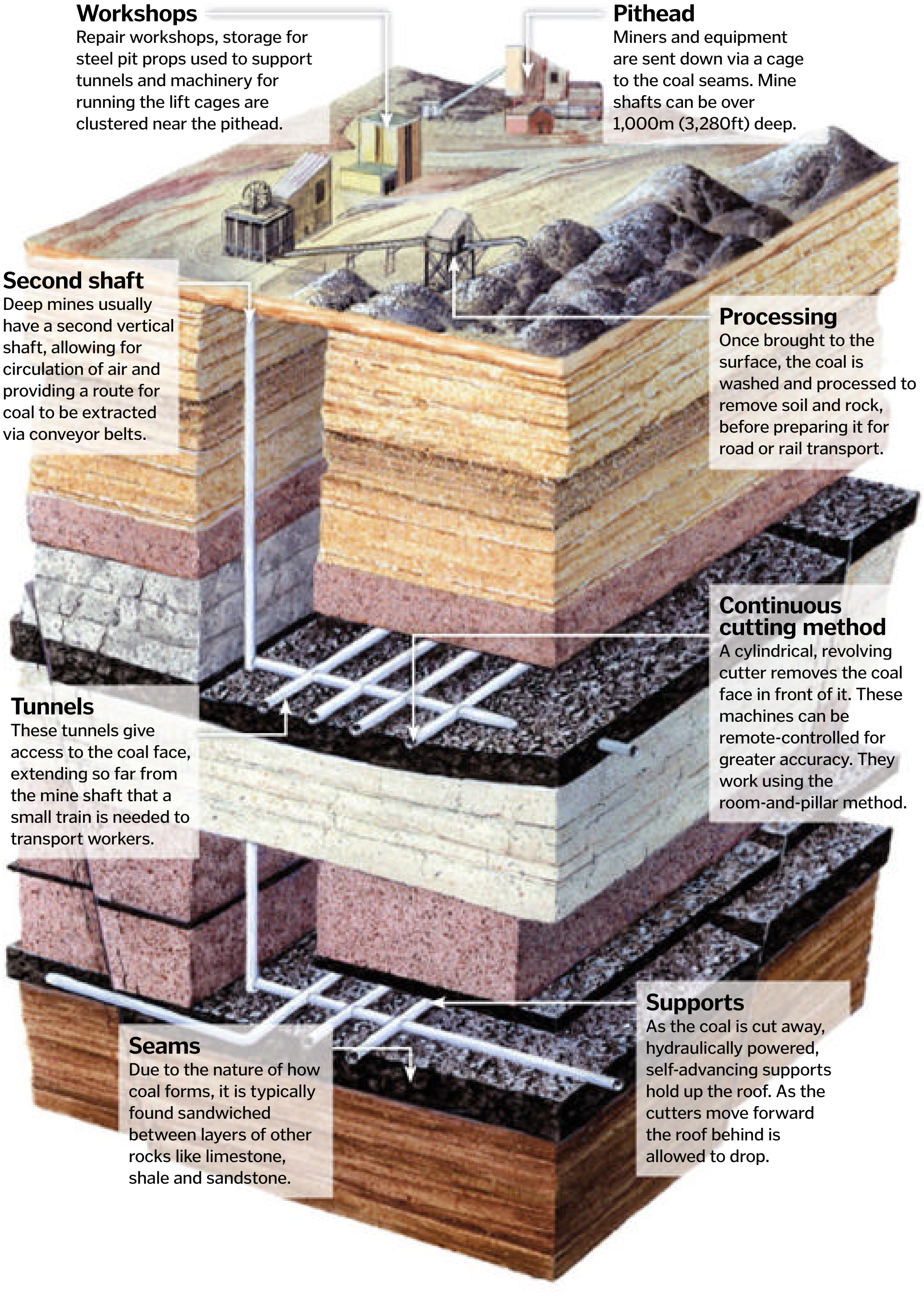
Incredibly thousands of worldwide seam fires account for as much as three per cent of carbon dioxide emissions. They also belch out other toxic gases and cause subsidence and destruction to their local landscapes.

They only stop burning when they exhaust their coal reserves or are extinguished through human intervention. Deep mine fires are put out by isolating them and pumping inert gases around the area of the blaze.

Fires nearer the surface, on the other hand, can be dealt with by pumping mud and water into the ground, followed by covering the area with an impermeable layer of sediments. The extent and depth of many of these fires though means they are impossible to put out.

## Coal mine level by level

**Take a tour of the main areas that make up a colliery**



**Workshops**
Repair workshops, storage for steel pit props used to support tunnels and machinery for running the lift cages are clustered near the pithead.

**Pithead**
Miners and equipment are sent down via a cage to the coal seams. Mine shafts can be over 1,000m (3,280ft) deep.

**Second shaft**
Deep mines usually have a second vertical shaft, allowing for circulation of air and providing a route for coal to be extracted via conveyor belts.

**Processing**
Once brought to the surface, the coal is washed and processed to remove soil and rock, before preparing it for road or rail transport.

**Continuous cutting method**
A cylindrical, revolving cutter removes the coal face in front of it. These machines can be remote-controlled for greater accuracy. They work using the room-and-pillar method.

**Tunnels**
These tunnels give access to the coal face, extending so far from the mine shaft that a small train is needed to transport workers.

**Supports**
As the coal is cut away, hydraulically powered, self-advancing supports hold up the roof. As the cutters move forward the roof behind is allowed to drop.

**Seams**
Due to the nature of how coal forms, it is typically found sandwiched between layers of other rocks like limestone, shale and sandstone.

© SPL

# Bomb-disposal suits

## How does this armour protect the technicians who disarm explosives?

Bomb-disposal suits are a form of specialised heavy body armour used by weapons specialists when diffusing explosive devices. They are used primarily by the military, but also see action in police forces. Their main role, not surprisingly, is to protect the wearer should the bomb unexpectedly detonate.

The suits are designed to mitigate the effects of intense heat, pressure and fragmentation – the debris from a bomb that flies off at high speed. This protection is achieved by combining several high-strength but low-weight materials such as Kevlar, Nomex, foams and a range of plastic composites, each layered and mixed to provide an all-round barrier to the effects of a blast.

As well as shielding the wearer, these advanced bomb suits are also responsible for keeping them connected to their team and as comfortable as possible. These factors are critical when out in the field, as often conditions can be extreme (such as in hot climates) and bomb disarmament is a very stressful operation. Built-in communication and ventilation systems ensure the technician stays informed and cool under pressure, respectively.

Over the past decade or so bomb-disposal suits have been in increasingly high demand, primarily due to the conflicts in Iraq and Afghanistan. This said, remotely controlled robots are now being used more and more to help avoid human casualties.

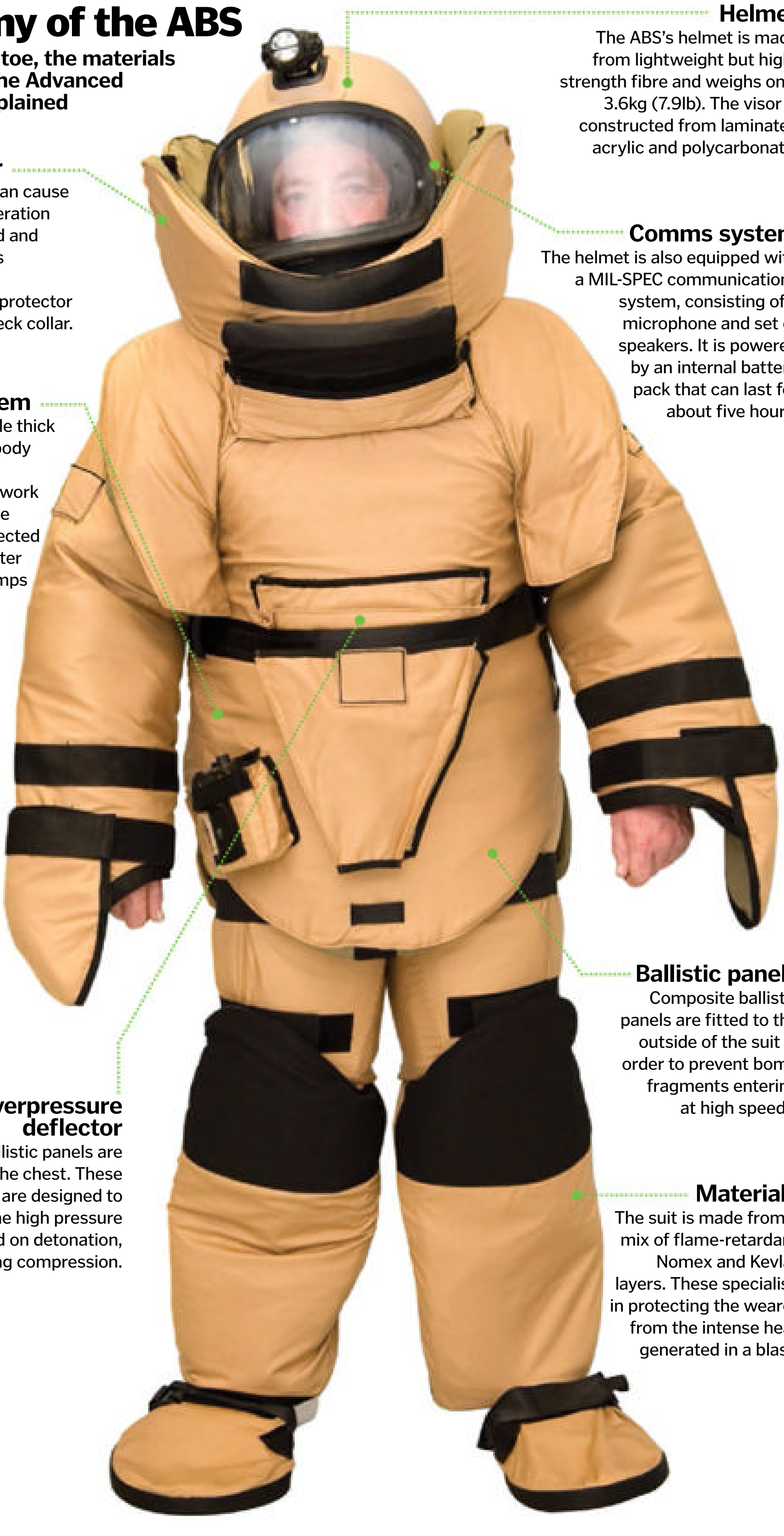
## The history of disarming bombs

The earliest references to bomb disposal stem from World War II in England. Nazi Germany had undertaken a large bombing campaign against Britain, and a number of the devices that were dropped landed but failed to detonate. This caused a spiked increase in civilian deaths, with unexploded bombs accidentally being triggered during people's day-to-day lives.

This led the British government to begin training volunteer members of the public in bomb-disposal techniques, with groups tasked with clearing sites laden with buried and undetonated weapons. Unlike bomb-disposal units today, these civilians wore no protective clothing and had only very basic tools, having to make do with spades, axes and wire cutters.

## Anatomy of the ABS

**From head to toe, the materials and tools of the Advanced Bomb Suit explained**



### Helmet

The ABS's helmet is made from lightweight but high-strength fibre and weighs only 3.6kg (7.9lb). The visor is constructed from laminated acrylic and polycarbonate.

### Raised collar

As an explosion can cause differential acceleration between the head and torso, each ABS is equipped with an articulated spine protector and supportive neck collar.

### Comms system

The helmet is also equipped with a MIL-SPEC communications system, consisting of a microphone and set of speakers. It is powered by an internal battery pack that can last for about five hours.

### Cooling system

Due to the multiple thick layers, a Nomex body suit with a woven capillary tube network is worn next to the skin. This is connected to a 2l (0.5ga) water reservoir that pumps ice-cold water around the ABS.

### Ballistic panels

Composite ballistic panels are fitted to the outside of the suit in order to prevent bomb fragments entering at high speeds.

### Lung overpressure deflector

Special rigid ballistic panels are placed over the chest. These offset panels are designed to absorb the high pressure generated on detonation, countering lung compression.

### Materials

The suit is made from a mix of flame-retardant Nomex and Kevlar layers. These specialise in protecting the wearer from the intense heat generated in a blast.

© Alamy

A furnace in action – temperatures inside the bowl can reach a fiery 1,650°C (3,000°F)

The tapped out molten steel cools in a ladle, but it's a race against time to use it before it cools too much

The molten steel is made into billets, which are huge rods of steel. They go from glowing red hot to grey in a matter of minutes

**THE STATS**
**CELSA STEEL MILL**

| | | | | | |
|---|---|---|---|---|---|
| DAILY SCREENING | 1,000 tons | MAXIMUM TEMP | 1,650°C | YEARLY OUTPUT | 1mn tons |
| FURNACE VOLTAGE | 275v | ELECTRODE COST | £4,000 | SLAG PRODUCTION | 18,000kg |

**DID YOU KNOW?** *Up until February 2014, China produced more crude steel than the rest of the world combined!*

# Making steel

## A behind-the-scenes visit to one of the biggest steelworks in Britain reveals how this essential metal is made

Steel is everywhere. Found in bridges, trains, computers and even your cutlery drawer, this alloy is one of the most widely used materials in the world. It is full of properties that make it the go-to choice for the construction of some of the world's most incredible structures, while being adaptable enough to be used for car doors and teaspoons, but how is this amazing construction product constructed itself? To answer this we went to the CELSA Steelworks in Cardiff, Wales, to get to grips with the process of creating steel.

Essentially, there are two main methods of making steel today. One is called basic oxygen steelmaking (BOS), which is how 60 per cent of the world's steel is currently produced. To begin this involves extracting iron ore from rocks in the ground. Next comes a process called smelting. Steelworkers fill a blast furnace with the iron ore, charcoal and limestone, pump vast amounts of air into the bottom – fuelling the fire that was created when an electrical charge was put through the system; this melts the iron down, allowing workers to 'tap' it out of the furnace. Pumping oxygen through the liquid iron oxidises the carbon content and, when it reduces to a certain level, steel is born.

The second process is called electric arc furnace (EAF), which instead of raw materials uses scrap steel to create new metal. It is this latter process which is employed at Cardiff's CELSA steelworks, all overseen by Ron Davidge, who has worked for several years in the steelmaking industry – first in the melt shop and then the control room.

"The EAF process starts in the scrapyard," Davidge tells us. "We put the scrap metal into the screening process and that separates the good steel from the rubbish. It's then loaded into the baskets and brought into the melt shop. We have different metal ratios based on the grade of steel we're making. The best steel has a copper content of around 20 per cent. Much more and the steel is weakened, as copper wire has a habit of breaking up under pressure."

The melt shop is the vast open building in which the really exciting part of steelmaking occurs – home to the furnace fire.

With a wrenching and a scraping, the lid is lifted off the furnace and the huge basket full of pieces of scrap metal is tipped into the furnace. Lifted up with the lid are three immense graphite electrodes, which are glowing red-hot.

"We have to keep the furnace at an incredibly hot temperature", explains Davidge, "because if we let it cool down it takes a huge amount of energy and time to reheat and we don't want to waste either of those. After we tip in the metal, the electrodes get lowered and we put an electrical charge through them that is conducted by the scrap. The electrodes have an angled base to increase their surface area."

When it is time for the second bucket of scrap to be lowered into the furnace, which we're told is currently running at around 1,650 degrees Celsius (3,000 degrees Fahrenheit), the lid is

HIW writer Jamie gets shown around the control room where everything at the plant is carefully monitored raised and an incredible ball of flame billows out of the container. The scrap is released into the pit where it is rapidly melted down into the liquid steel bath.

"The walls of the furnace are lined with silica brick, which has a very high melting rate. Even so, the shelf life of even good-quality brick only lasts about three weeks before it needs to be changed. We have to make sure we protect our furnace because they're expensive", says Davidge. "The furnace is also lined with manganese and slag from previous meltings to provide some extra protection."

It is at this point in the process that the BOS and EAF steelmaking methods converge and follow the same path (see diagram, right).

Once the majority of the steel has been melted down, a burst of oxygen is sent through the steel oxidising the contents until most of the impurities are removed and the perfect level of carbon content is reached.

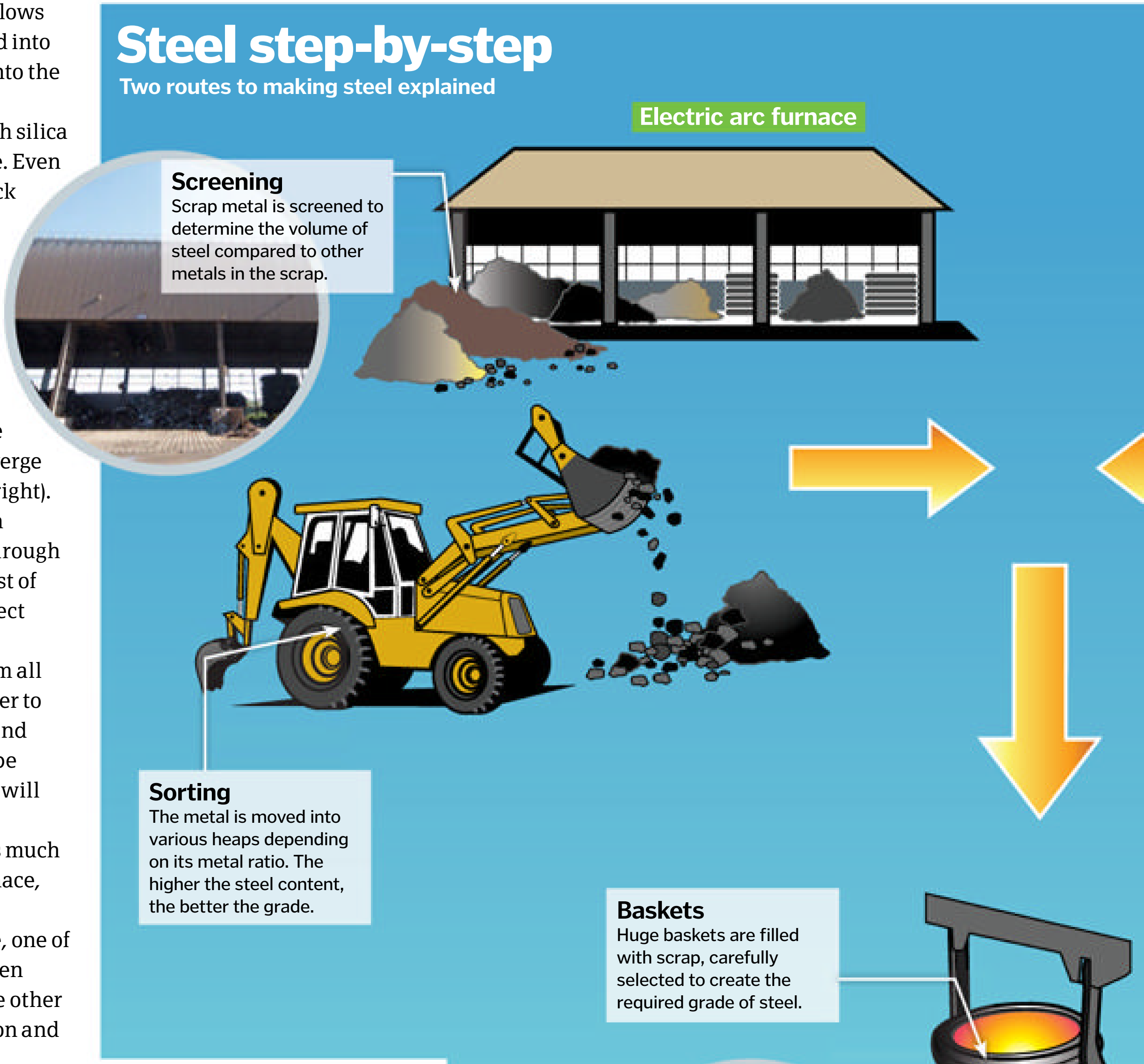
Slag is the thick substance created from all the waste products in the process. In order to remove this, the furnace is tipped back and forth a few times, allowing the waste to be pushed out of the slag door. This process will often lose a bit of liquid steel but it is an acceptable sacrifice at this stage. After as much slag as possible is removed from the furnace, the tapping process can begin.

There are two pipes below the furnace, one of which allows a stream of 145 tons of molten steel to run down it into a bath, while the other contains metals and alloys, such as silicon and

The temperature on the melt shop floor becomes almost unbearably hot as the furnace roars into action

## Steel step-by-step

Two routes to making steel explained

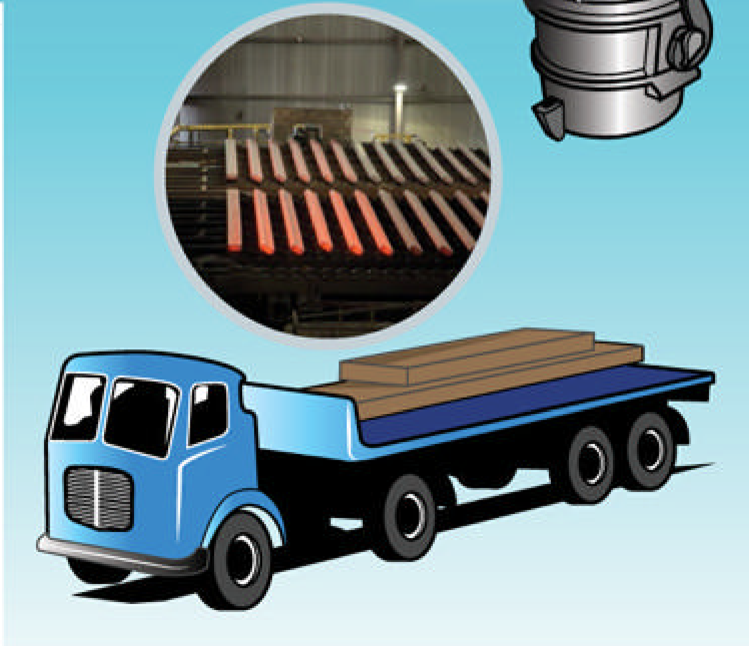


**Electric arc furnace**

**Screening**
Scrap metal is screened to determine the volume of steel compared to other metals in the scrap.

**Sorting**
The metal is moved into various heaps depending on its metal ratio. The higher the steel content, the better the grade.

**Baskets**
Huge baskets are filled with scrap, carefully selected to create the required grade of steel.



RECORD BREAKERS

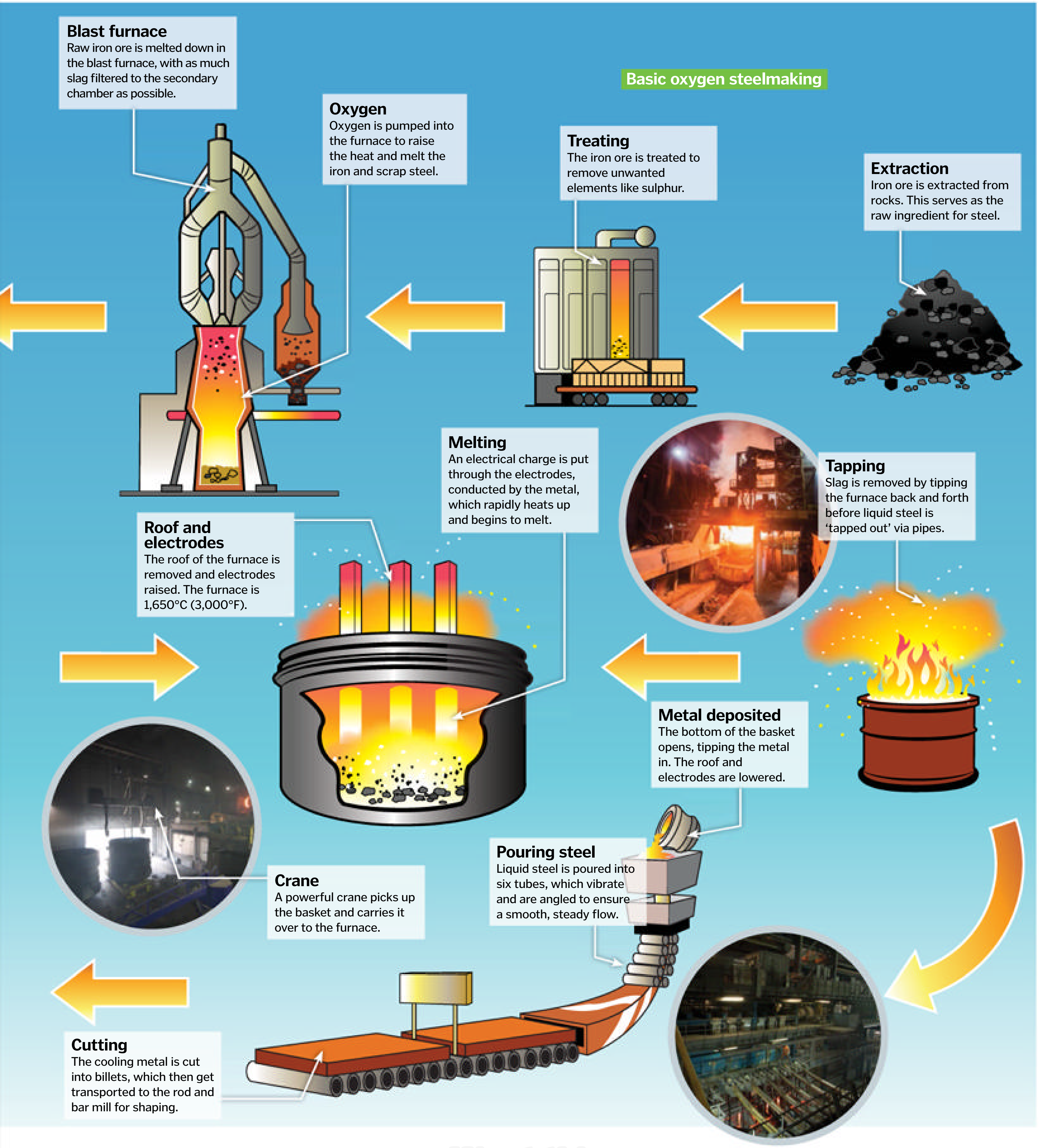
MEGA FURNACE

# 6,000M³

## BIGGEST FURNACE ON EARTH

The largest furnace in the world is Furnace 1 at the Gwangyang Steelworks in South Korea. It has a giant capacity of 6,000 cubic metres (212,000 cubic feet).

**DID YOU KNOW?** *There are more than 3,500 grades of steel, 75 per cent of which have been developed in the last 20 years*



**Basic oxygen steelmaking**

**Extraction**
Iron ore is extracted from rocks. This serves as the raw ingredient for steel.

**Treating**
The iron ore is treated to remove unwanted elements like sulphur.

**Oxygen**
Oxygen is pumped into the furnace to raise the heat and melt the iron and scrap steel.

**Blast furnace**
Raw iron ore is melted down in the blast furnace, with as much slag filtered to the secondary chamber as possible.

**Crane**
A powerful crane picks up the basket and carries it over to the furnace.

**Roof and electrodes**
The roof of the furnace is removed and electrodes raised. The furnace is 1,650°C (3,000°F).

**Melting**
An electrical charge is put through the electrodes, conducted by the metal, which rapidly heats up and begins to melt.

**Metal deposited**
The bottom of the basket opens, tipping the metal in. The roof and electrodes are lowered.

**Tapping**
Slag is removed by tipping the furnace back and forth before liquid steel is 'tapped out' via pipes.

**Pouring steel**
Liquid steel is poured into six tubes, which vibrate and are angled to ensure a smooth, steady flow.

**Cutting**
The cooling metal is cut into billets, which then get transported to the rod and bar mill for shaping.

manganese, which will be poured into the molten metal mixture to create the right grade of steel for that particular batch.

The bath is analysed and more tweaks are made to the constitution of the steel before it is left to cool slightly, developing a dark, bubbling surface skin, looking a bit like a slightly over-grilled cheese sandwich.

The next stage is to turn that molten steel into steel bars and rods. This is done by craning the container up onto a huge rotor arm, which holds one full bath in waiting and another over a trough. This trough has six exit points, through which the molten metal flows. In order to keep it flowing evenly, the trough vibrates slightly, which keeps the liquid metal constantly moving. The exit points are copper pipes, which drop at a slight angle before levelling out to a horizontal half-pipe, much like a kamikaze water slide.

"As well as the vibrating pipes, the angled drop is designed to keep the stream consistent and smooth," Davidge says. "Too sharp a drop and cracks could appear, too shallow a drop and the metal will be too cool for it to be cut."

The constant flow pushes the molten metal along the line, where it cools surprisingly rapidly. Mechanical cutters are set up, again at a slight angle so it can cut the metal in a straight line as it continues to move in a process called

## How do we make steel stainless?

Steel can be made stainless by the adding of at least 10.5 per cent chromium to the melt. When cooled, the chromium protects the steel from rusting by providing an oxide layer on the surface to protect the steel. As the chromium has very low levels of reactivity, it doesn't rust, keeping your cutlery shining for years.

The origins of stainless steel are fairly complicated. As far back as 1821, scientists noticed that alloys of chromium and iron were resistant to rust, but it wasn't until 1913 that the practice took off. Sheffield's Harry Brearley, looking to create rifle barrels that didn't corrode, discovered that steel-chromium alloys with at least six per cent chromium didn't oxidise. Further studies led him to create a steel product with 12.8 per cent chromium, which is widely considered the first genuine stainless steel.

The tapping of the molten steel is an incredible sight. Extra elements like silicon are added at this stage to create the right grade of steel

## A brief history of steel...

### 800 BCE

The Iron Age begins. It follows the Bronze Age and heralds the start of iron as the main metal for making tools and weapons.

### 206 BCE

During the Han Dynasty, Chinese metalworkers produce an early form of heat-treated steel, as well as high-carbon cast iron.

### 1692

The first recorded creation of steel in Sheffield. It is called blister steel and is formed by using charcoal to melt wrought iron and increase the carbon content to create steel.

### 1708

A cast iron foundry is established in Shropshire that uses coke, a substance created by heating coal, to make cast iron – free from impurities caused by charcoal and coal.

### 1751

The crucible method of creating steel is developed in Sheffield, in which steel is melted in a crucible to separate slag, which can then be removed.

**DID YOU KNOW?** *William Kelly, the inventor of modern steelmaking, had to sell his patent to Henry Bessemer due to bankruptcy*

Many workers at the plant have been at the site for decades. One slip-up could ruin an entire day's production

continuous casting. The swiftly cooling billets turn from red to grey in front of our eyes, before being stacked on the back of a huge lorry to be transported to the rod and bar mill where they will be shaped.

The whole process takes around 45 minutes from the moment the first basket of steel is deposited in the furnace to the point at which the container has finished emptying its load of molten steel into the trough.

Any delay would lead to the entire process becoming much less efficient, whether it's the furnace being underused, the molten metal cooling too much and needing reheating or the billet stream grinding to a halt. The plant tends to work 24 hours a day, seven days a week, with maintenance being done in brief periods of downtime or scheduled shutdowns.

We continue outside to take a quick look around the 'slag shed', where all the waste material is deposited. However, this will not get thrown away as the slag can be sold on to companies as a road-building product.

Inside a steelworks is hot, noisy and dusty (they create 50 tons of dust every day) and the pressure to get things right is immense as one slip-up can compromise an entire day's work. Steel is pretty big business and to experience the raw power of that furnace and the dedication of the workers to ensure hundreds of tons of top-quality steel gets produced every day was incredible.

Steel, in its many forms, is a vital material in today's society and its strength, durability and flexibility is only mirrored by the people and the process that creates it.

## ON THE MAP

### Biggest steel producers by continent

1 China: 62mn tons
2 USA: 6.8mn tons
3 Germany: 3.6mn tons
4 Brazil: 2.6mn tons
5 South Africa: 0.5mn tons
6 Australia: 0.4mn tons

Source: World Steel, Feb 2014

## Iconic steel structures

### 1 Sydney Harbour Bridge

One of the most iconic structures in the world, the Sydney Harbour Bridge spans 1,149m (3,770ft) with the signature arch stretching 503m (1,650ft). The steelwork weighs 52,800 tons and is made of a special steel blend containing Pearlite, which bumped up the carbon content and in doing so increased the strength to 1.3 times that of normal steel.

### 2 Willis Tower (formerly Sears Tower)

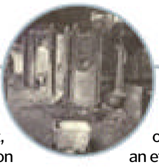
Completed in 1974, the Sears Tower overtook the Empire State Building as the USA's largest steel building, standing 442m (1,450ft) high. It made use of Khan's Bundled Tube principle, which involves a number of steel pipes secured together to create a rigid superstructure that maximises the steel used for efficiency.

### 3 RMS Titanic

A 2008 study suggested the steel that went into making this 46,000-ton ship could have aided its downfall. As steelmaking was still in its infancy, the ship's metal was ten times as brittle as modern steel, due to open hearth furnaces allowing sulphur, oxygen and phosphorus to infiltrate the metal.

**1784**

The puddling furnace is developed by Englishman Henry Cort, which decreases carbon content in iron by stirring.

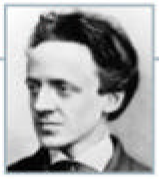


**1856**

William Kelly and Henry Bessemer discover blowing oxygen through iron creates an efficient way of making steel and they patent this idea.

**1876**

Sidney Gilchrist Thomas adds limestone to the mixture to remove phosphorus, which makes steel brittle.



**1913**

Harry Brearley creates stainless steel by mixing chromium in with the steel mixture to form a corrosive-resistant layer.

**2003**

A patent was filed by Morris Dilmore and James D Ruhlman for Eglin steel, a very strong steel blend with low to medium carbon content. This is thought to be the strongest steel in the world.

© Peters & Zabransky

# Inside battle simulators

## A revolutionary new system for training the soldiers of tomorrow

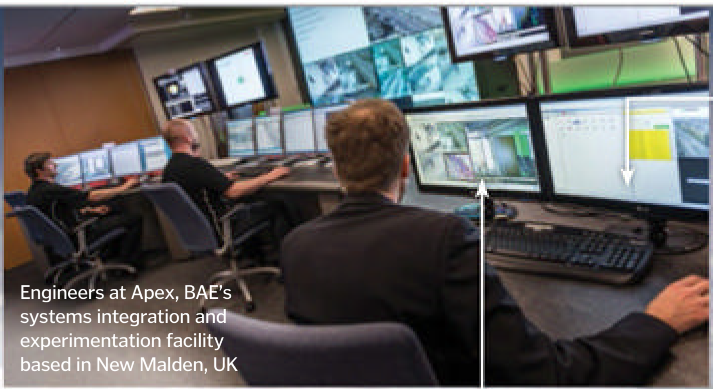
Training recruits to use some of the world's most expensive and complicated military technology is no easy task. Millions of pounds' worth of military hardware needs to be placed in the hands of learners and, while these future fighters are carefully managed, the run-time costs to operate trial mission after trial mission are quite simply astronomical.

After years of development, defence company BAE has created a virtual battle training system – a simulation network that runs through live scenarios with several players simultaneously. Indeed, thanks to the Dedicated Engineering Network (DEN), simulators controlling virtual Type 45 destroyers, Typhoon fighter jets and even E-3D Sentry aircraft can be brought together in a simulated combat environment and put through their paces in a range of scenarios combining land, sea and air tech.

In doing this, not only can the most advanced military hardware be tested together as one functioning unit, but trainees and professionals alike can run through missions without even having to set foot outside.

This not only saves money but also allows for a greater range of scenarios to be played out in a short period of time. Further, thanks to DEN securely managing integration with Ministry of Defence (MoD) networks, scenarios can be witnessed by commanders and decision-makers remotely, granting an unprecedented access to information.

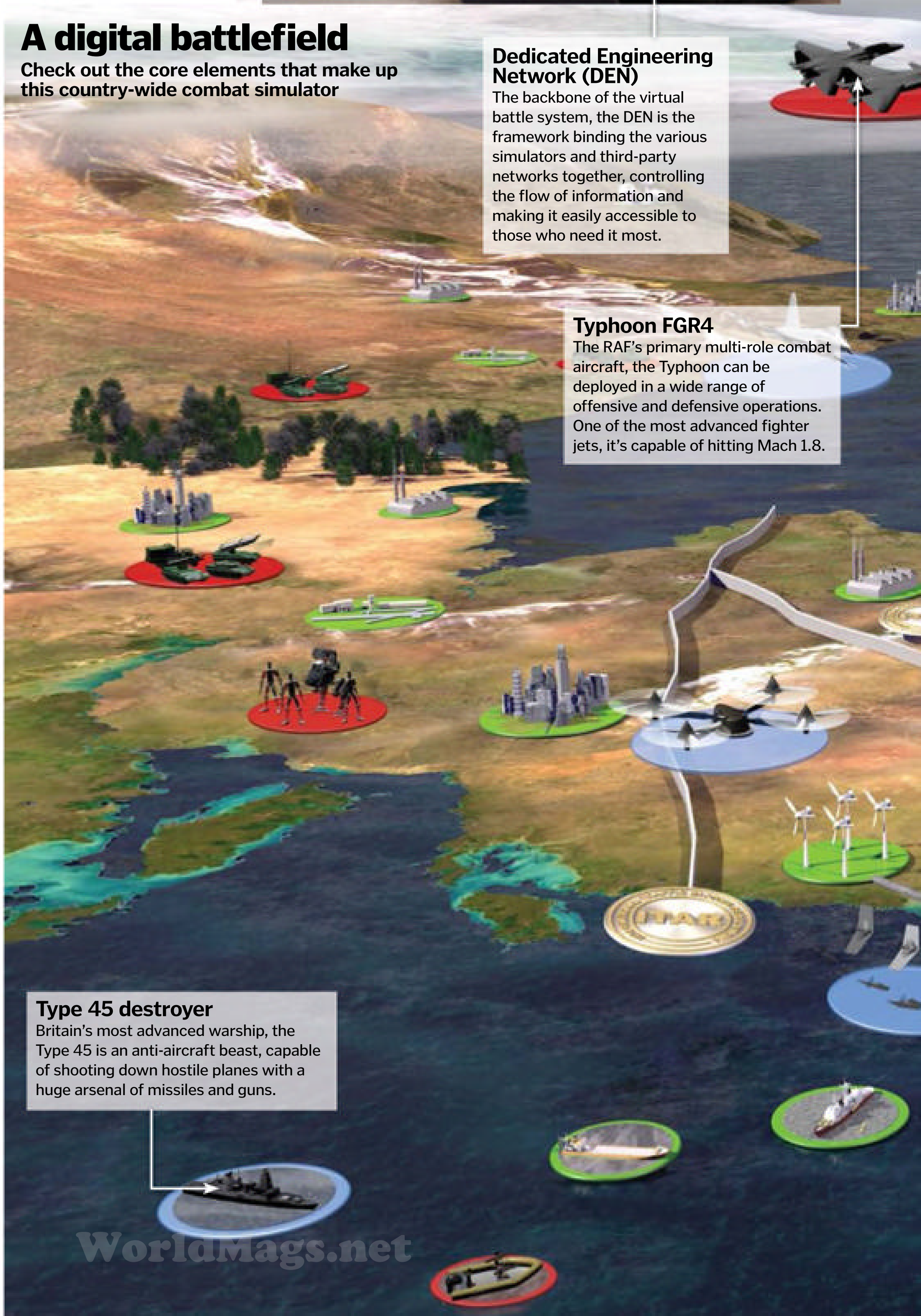
The system is still under testing, with a simulator at BAE's Warton facility in Lancashire, UK, emulating four Typhoons, partnered with two other simulators at different sites which emulate an E-3D Sentry AEW1 and a Type 45 destroyer. With a high level of success to date, more trials are already planned over the next 18 months, with more simulated combat vehicles looking to be integrated – the most notable being the state-of-the-art F-35 Lightning II fighter jet.



Engineers at Apex, BAE's systems integration and experimentation facility based in New Malden, UK

## A digital battlefield

**Check out the core elements that make up this country-wide combat simulator**

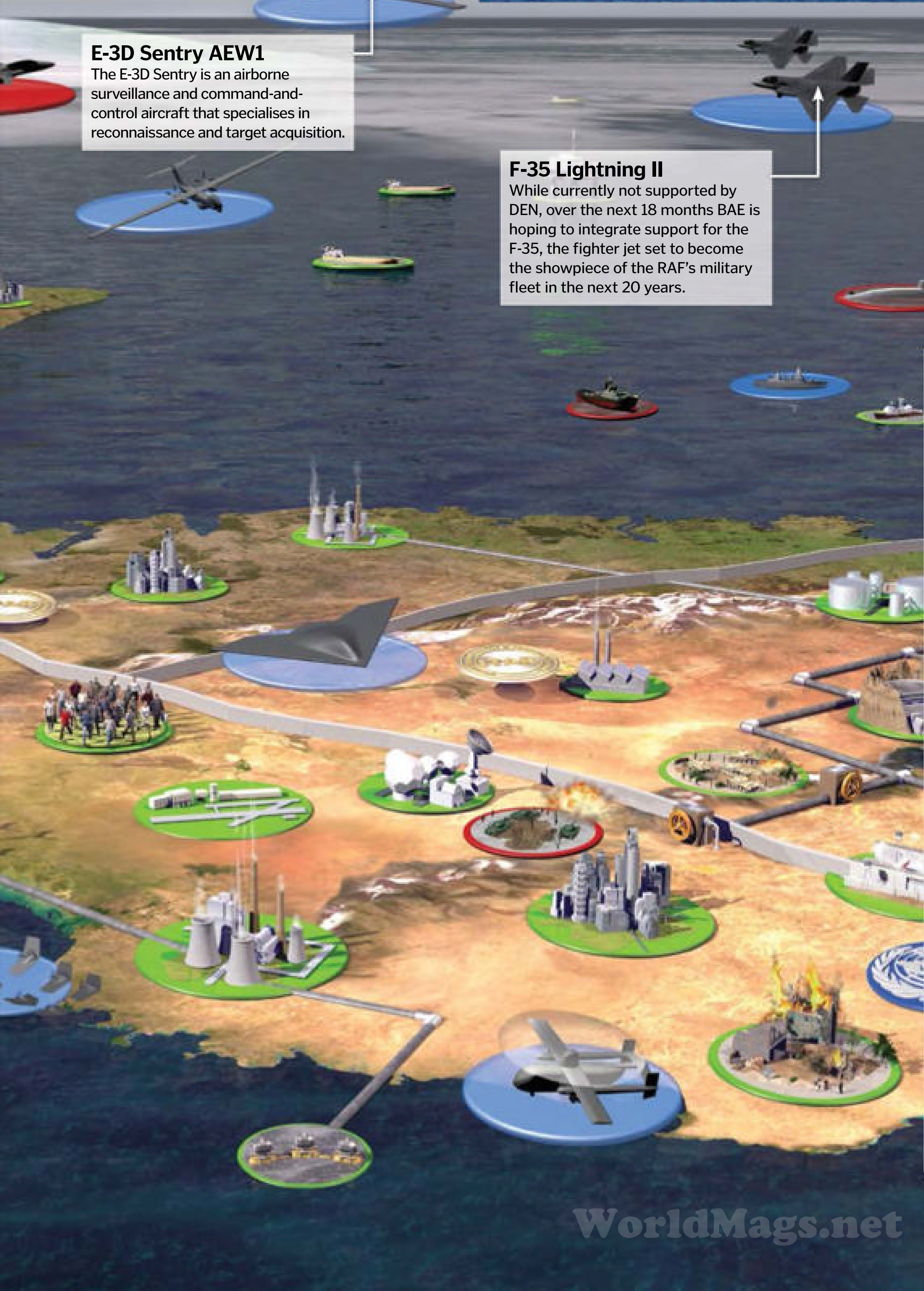


**Dedicated Engineering Network (DEN)**
The backbone of the virtual battle system, the DEN is the framework binding the various simulators and third-party networks together, controlling the flow of information and making it easily accessible to those who need it most.

**Typhoon FGR4**
The RAF's primary multi-role combat aircraft, the Typhoon can be deployed in a wide range of offensive and defensive operations. One of the most advanced fighter jets, it's capable of hitting Mach 1.8.

**Type 45 destroyer**
Britain's most advanced warship, the Type 45 is an anti-aircraft beast, capable of shooting down hostile planes with a huge arsenal of missiles and guns.

**DID YOU KNOW?** *The trial DEN demonstration was the first of its kind in Europe and linked four sites across the UK*



### JMNIAN network

BAE's virtual battle system will be interoperable with the MoD's Joint Multi-National Interoperability Assurance Network (JMNIAN), which provides a hub for all of the armed forces. The DEN simulator can be accessed from numerous bases and defence facilities.

### E-3D Sentry AEW1

The E-3D Sentry is an airborne surveillance and command-and-control aircraft that specialises in reconnaissance and target acquisition.

### F-35 Lightning II

While currently not supported by DEN, over the next 18 months BAE is hoping to integrate support for the F-35, the fighter jet set to become the showpiece of the RAF's military fleet in the next 20 years.

Two of the advanced military vehicles that soldiers can play out battle scenarios with using DEN

### ① New Malden facility

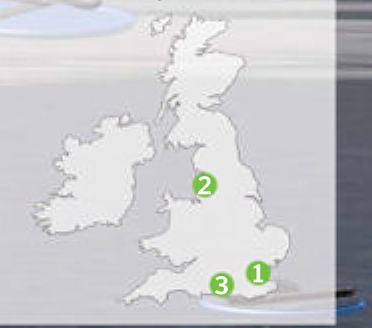
The E-3D Sentry is simulated on its own at BAE's New Malden site in London, linked to the simulated environment by BAE's DEN.

### ② Warton facility

Four virtual Typhoons are simulated from BAE's facility in Lancashire and link in to the battle system.

### ③ Broad Oak facility

The simulator for the system's Type 45 destroyer is located at BAE's Broad Oak facility, near the famous Portsmouth dockyard.

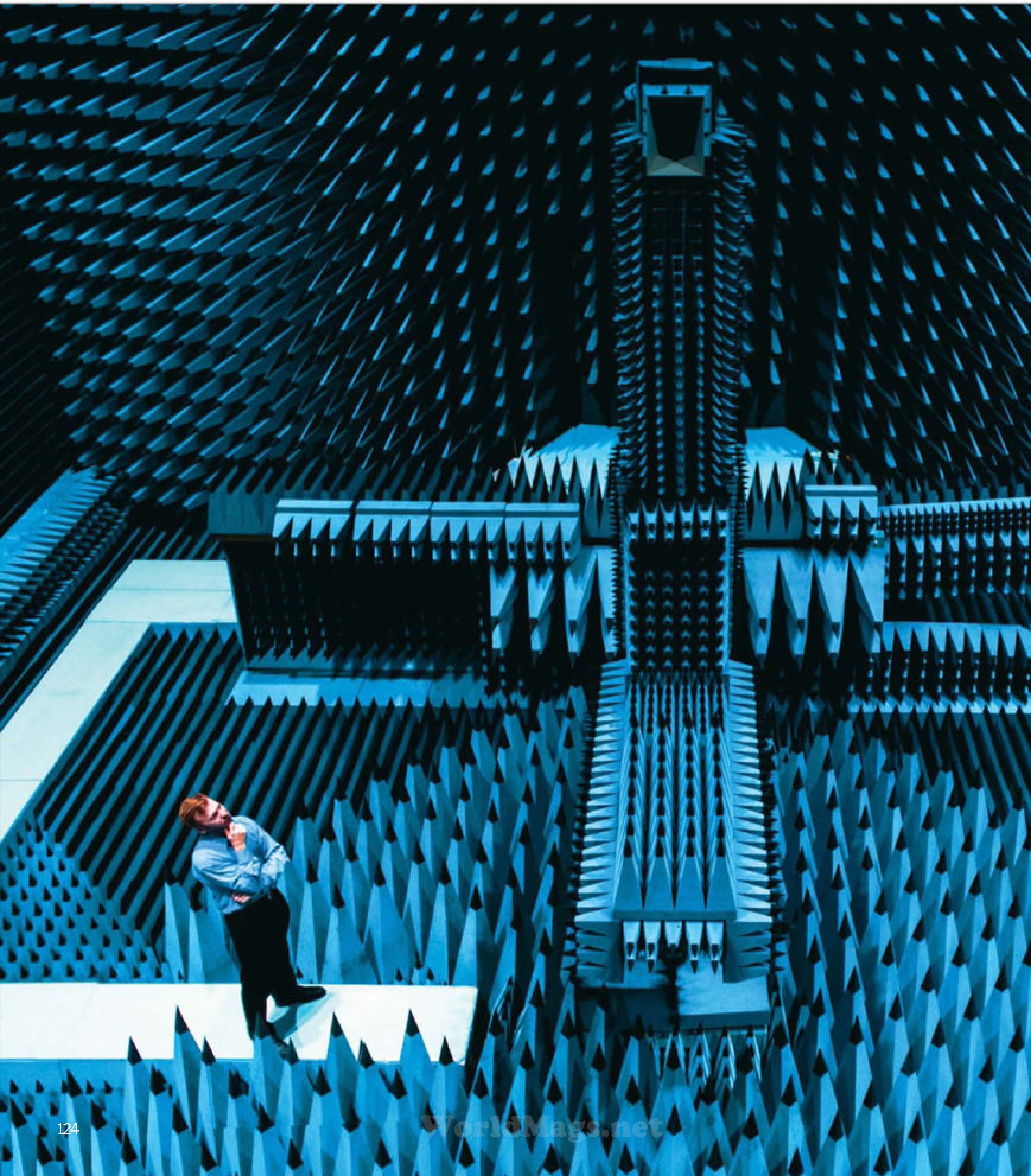


## A virtual rival

Facing up against BAE Systems' DEN in the battle for virtual combat training supremacy is American defence contractor Lockheed Martin's Multi-Function Training Aid (MFTA). The MFTA is pitched as being a reconfigurable platform for a wide range of military vehicles, with the system capable of simulating fixed-wing multi-crew aircraft, helicopters, landing hovercrafts, fast attack boats, trucks and even utility vehicles.

The system is based on Lockheed's own Prepar3D simulation software, with a comprehensive suite of simulated controls, multitouch glass panels and authentic cockpit layouts (pictured below) allowing the user to adapt quickly to their specific training vehicle. Data for the system comes courtesy of the WGS-84 database, allowing things like traffic, weather and other factors to be realistically replicated. Throw in extras like a built-in motion platform, electro-optical, infrared and radar sensors as well as real heads-up displays and it's obvious that the MFTA offers new soldiers a valuable insight into life on the battlefield.

© BAE Systems; Lockheed Martin



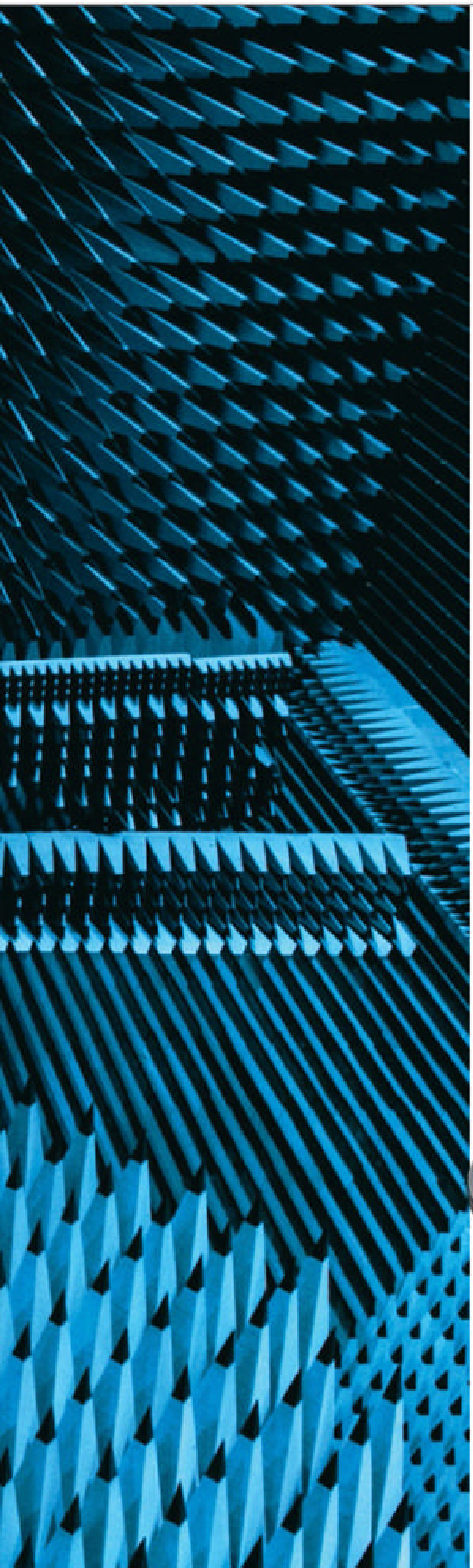
**RECORD BREAKERS**
**VERY HUSH-HUSH**

**99.99%**

## MOST SOUNDPROOF ROOM

The anechoic test chamber at Orfield Laboratories in Minneapolis, USA, is so quiet it can induce hallucinations. It absorbs 99.99 per cent of sound. The longest anyone has spent inside is 45 minutes.

**DID YOU KNOW?** *The opposite is a reverberation room where hard, smooth, reflective walls intentionally bounce sound waves*



# The quietest rooms on Earth

How do the walls in an anechoic chamber dissipate sound waves so all you hear is your own heartbeat?

Anechoic chambers are echoless rooms, designed to prevent the reflection of sound waves, but can work just as well at stopping electromagnetic radiation in its tracks. This enables accurate testing of acoustics and electrical equipment without interference from echoes.

To prevent the rebounding of audible sounds, anechoic chambers are lined with fibreglass wedges, covering the walls, floor and ceiling to create an uneven surface. Sound wave energy is absorbed by the fibreglass and transferred into the body of the wedge, where it dissipates. Any reflected sound bounces off at an angle and hits an adjacent wedge, eliminating echo.

Anechoic chambers can also prevent the reflection of electromagnetic radiation, including radio waves, and are used to test antennas and radar. These waves can't be absorbed by pure insulators or conductors, as they're ineffective at accepting energy. Therefore, the material lining radio anechoic chambers is designed to mix the properties of both insulators and conductors.

Rubberised insulating foam is impregnated with conductible metal, such as iron, and formed into mini pyramids. These capture and divert the electromagnetic waves, preventing them from reflecting back into the room. The pyramids' length is designed to match the frequency of the electromagnetic waves being tested, with longer pyramids for low frequencies and shorter ones for high frequencies.

Anechoic chambers are not just free from echoes, but often soundproof as well, and may be encased in concrete or suspended on shock absorbers to prevent noise entering from the outside. The same is true of radio anechoic chambers, which are protected from external sources of electromagnetic radiation by a Faraday cage – a mesh of conducting material that diverts any incoming electrical activity around the room without letting it in.

## The history of echoless rooms

First developed in the United States back in the Forties, wedge-lined anechoic chambers were originally used for acoustic testing, housed in concrete structures for soundproofing.

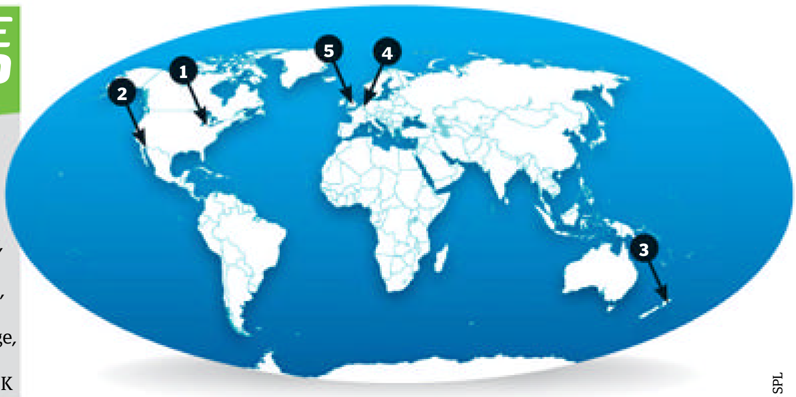
Modern chambers are similar in many ways, but the design has been refined to achieve more efficient loss of audible vibration, particularly at lower frequencies. They are also better insulated from external sources of interference, and are often mounted on sprung floors. This technique is also used in concert halls to protect them from any vibration in the building.

Radio anechoic chambers were developed in the Sixties and used the same principles to dissipate energy. To ensure that there are no unwanted emissions or reflections of electromagnetic radiation in the chamber, all equipment is insulated in nonconducting materials.

**ON THE MAP**

### Anechoic chambers around the world

**1** Orfield Laboratories, Minnesota, USA
**2** Benefield Anechoic Facility, California, USA
**3** The University of Auckland, New Zealand
**4** Compact Payload Test Range, Noordwijk, the Netherlands
**5** The University of Salford, UK



© SPL

# Building demolition

## What goes up must come down – but how exactly do we recycle giant buildings?

An excited hush falls across the deserted tower block. Neighbouring residents look on as the police helicopter overhead double-checks that the exclusion zone is clear. The countdown reaches zero and the button is pushed. An explosive shockwave ripples through 1,500 separate charges, shattering the supporting concrete columns. With surprising grace, the huge 24-storey tower block folds downwards into a billowing skirt of dust.

The mere seconds it takes for the building to come crashing down might be the only part that makes the local evening news, but the real work can extend for months before and after the big bang. Mark Coleman is the managing director of Coleman & Company – one of the UK's leading demolition firms. In an exclusive interview, he talks us through the key stages in the high-rise demolition process.

The first four or five months are spent planning, he explains: "The Health and Safety Executive, the local council… the people who are being evacuated, the firearms and explosives division of the police: you've got to convince these people that you are competent. You have a structural engineer to ensure that up to the point of pressing the button, the building will stand up; an explosives engineer to make sure that at the point of pressing the button, the building will fall down, and that it will fall down at the right place, not spread too far and not damage anything."

Work begins by stripping the building completely. Specialist contractors remove toxic materials, such as asbestos. Furniture, fitted cabinets, electrical wiring, plumbing, flooring and even the windows and plasterboard panels are all taken out as well. In fact, Coleman & Company aims to recycle as much as 98 per cent of a building during the demolition process, and it's much easier to do that *before* it is reduced to rubble. "We don't even throw settees in the skip any more," says Coleman. "We take the fabric off and that gets shredded, we strip the wood, that gets recycled and any metal in there goes into the scrap metal skip."

Once the building has been reduced to a concrete shell, the next six to eight weeks are

## 5 TOP FACTS
EXPLOSIVE TYPES

**Dynamite**
1 Invented by Alfred Nobel, dynamite consists of unstable nitroglycerine mixed with fine clay to make it safer. It needs careful handling, and isn't used for demolition anymore.

**PETN**
2 Pentaerythritol tetranitrate is chemically similar to nitroglycerine and is one of the ingredients of Semtex. In demolition, PETN is used as the detonating cord core.

**TNT**
3 Trinitrotoluene is a stable high explosive used in demolition. It needs another more sensitive explosive to set it off, and can be melted and poured into moulds without detonating it.

**RDX**
4 Also known as hexogen, RDX is even more powerful than TNT. It is used as a cutting charge in demolition to sever stronger structural steel beams.

**Tovex**
5 This water-gel explosive which includes ammonium nitrate has replaced dynamite in many cases – mainly because it's less toxic and is generally safer to use and transport.

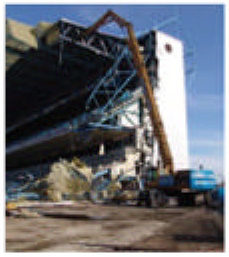
**DID YOU KNOW?** *Police helicopters use thermal-imaging cameras on demolition days to look for anyone still in the building*

## High-stakes demolition

When it was built in 1908, the headquarters of the Singer sewing machine company in Manhattan, New York, was the tallest building in the world. When it was demolished in 1968, it was the tallest building ever to be torn down. If you don't count the terrorist destruction of the World Trade Center in 2001, it still is. Since Lower Manhattan is so crowded, explosive demolition was out of the question in this case. Instead, the 47-storey building was demolished the same way it was built – with a crane on the top and crews of workers who dismantled it floor by floor.

## Types of demolition

**We weigh up the pros and cons of three deconstruction methods (1 = low/5 = high)**



| | Machines | Explosives | Hydraulic jacks |
|---|---|---|---|
| Noise | 5 | 3 | 1 |
| Risk level | 4 | 5 | 2 |
| Disruption | 5 | 3 | 2 |
| Total time | 3 | 4 | 2 |
| Expense | 3 | 4 | 5 |

Jets of water are often blasted at buildings during demolition to reduce dust levels

spent ‘pre-weakening’ the structure. “This does two things,” Coleman continues. “One, it allows you to get access [for the explosive charges], but two, it also allows you to use fewer explosives to collapse it. Typically, you remove 1.5-metre (4.9-foot) rectangular arches out of a wall and then try to demolish the next two to three metres of concrete by the use of explosives. BS5607, which is the British Standards code for the Safe Use of Explosives, says you need to minimise the amount you use, so you're not blasting the hell out of it and sending concrete flying all over the place.“

The type of explosive used depends very much on the building. A tower block is a relatively weak structure, held up by simple reinforced concrete pillars. These can be destroyed using detonating cord. This resembles coaxial TV aerial cable, but the core is filled with PETN (pentaerythritol tetranitrate) high explosive. This ‘det cord’ is used as a high-speed fuse for large jobs; it burns at about 7.2 kilometres (4.5 miles) per second, but for tower blocks it has enough explosive power to get the job done by itself. “When you start moving into bigger, more industrial structures – eg power stations and heavy concrete or steelwork – it's a different ball game altogether,“ explains Coleman. “You are now into shaped, cutting charges. You use these to induce failure in the already pre-weakened section – to blast out the remaining piece that's holding the whole thing together.“

While the drilling and pre-weakening is going on, arrangements have to be made for the nearby residents. “Typically on an inner city site, you can be evacuating a few hundred properties and catering for a few thousand

## Demolition machines

### 1 Wrecking ball
A steel ball weighing up to 5,400 kilograms (12,000 pounds) is swung from a long chain. At one time the most common demolition machine, the wrecking ball is used much less now because it has a shorter reach than modern excavators.

### 2 High-reach excavator
A variant of the JCBs used to dig ditches, the high-reach excavator has a much longer boom arm and a wide base to provide a stable platform. The tallest excavators can reach 67 metres (220 feet) – about 23 storeys – and weigh 200 tons.

### 3 Concrete pulveriser
The concrete pulveriser is a huge hydraulic hammer. They can weigh as much as six tons, and are used to break up thick foundation slabs and chisel away at stubborn concrete pillars.

### 4 Shears
This attachment chews up walls and beams using powerful jaws. Large ones can open up to 1.2 metres (four feet) wide and weigh over four tons. Their bite force is 145 tons – about 40 times as much as a Tyrannosaurus rex!

### 5 Brokk robot
Where access is restricted or the maximum loading of a supporting floor is limited, specialist robotic demolition machines offer much higher power-to-weight ratios than manned excavators. The Brokk 50 can pass through ordinary doorways and climb stairs.

people on the day, so it's a bit like a military operation," says Coleman. "You have to survey and contact each of the properties for any issues such as security and pets. We have to create a safe, sterile environment, which is generally [equivalent to] three times the height of the structure. So, say, if you have a building that is 50-70 metres [164-230 foot] high, you are talking about an exclusion zone in the region of 150-200 metres [492-656 feet].

"Generally, we try to negotiate our way through it without money changing hands. So if you're close to the structure, we'll put you up for the weekend at a hotel. If you're not too close we might look at other proposals, such as locking you into the building and putting a policeman outside. It's all about finding [the safest] process. If you're standing within a few metres of the building you're going to get squashed, but if you're 50 metres [164 feet] away you've got no problem."

A week or two before the day of the demolition, the detonating cord is fed into the holes and grouted firmly in place. This improves the detonation efficiency as the expanding gas from the explosives has nowhere to go and the force is concentrated into the concrete wall.

But it also prevents the explosives from being stolen by opportunist thieves or terrorists. There is no risk of accidental explosion without the detonators, but to be safe the ground floor of the demolition site is still guarded around the clock by specialist security teams.

Demolition day itself is nearly always on a Sunday to minimise the disruption to local traffic and businesses. Around 5am, workers begin surrounding the perimeter of the demolition exclusion zone with security fencing. "Around the fence zone we have sentries, and they all have to have a line of sight between each other so they can maintain visual security of the zone in the event of the radios not working," Coleman explains. "Each sentry will have a police officer with them, so if there is a breach the police will deal with it."

The spider's web of detonation cord laced through the building is brought together into bunches at strategic points, and at about 7am, the explosives engineer begins attaching the detonators to each bunch. Even at this point, key connections are left open in order to ensure absolute safety: "They wait there ready until the team can say, guaranteed, everyone is out. Then we'll start a ten-minute countdown, with a series of final connections carried out in the last few minutes. There's a series of horns that sound to keep everybody alert. There's an electric atmosphere in the air and a deathly silence falls.

"When we're doing the countdown, we'll count from 20 down to ten, and that will be audible over the radios, then you'll hear a shot go, which we use to frighten any birds out of the building. And then everyone will think 'What's happening?' But we've actually started the real ten-second countdown; the purpose of the radio silence is that in those crucial seconds, if someone needs to [stop the blast], all they need to do is say, 'Abort!'."

Incredibly, it takes between just three and five seconds for a 45,000-ton tower block to crumble down into a pile of rubble. Once the dust has settled, the explosives engineer inspects the debris to be certain that all the explosives detonated. Next excavators and street-sweeping machines and workers with brushes and brooms move in to clean up the surrounding area, and the neighbouring

## How to implode a tower block

**A step-by-step guide to blowing up several thousand tons of concrete and steel with maximum safety and efficiency**

**Risk assessment**
Experienced structural engineers survey the building to make sure it can be imploded safely.

**Strip the building**
All glass, soft furnishings, asbestos, wiring, plumbing and plasterboard are removed, leaving just the concrete shell.

**Setting charges**
Holes are drilled along every load-bearing section, filled with detonation cord and grouted in place.

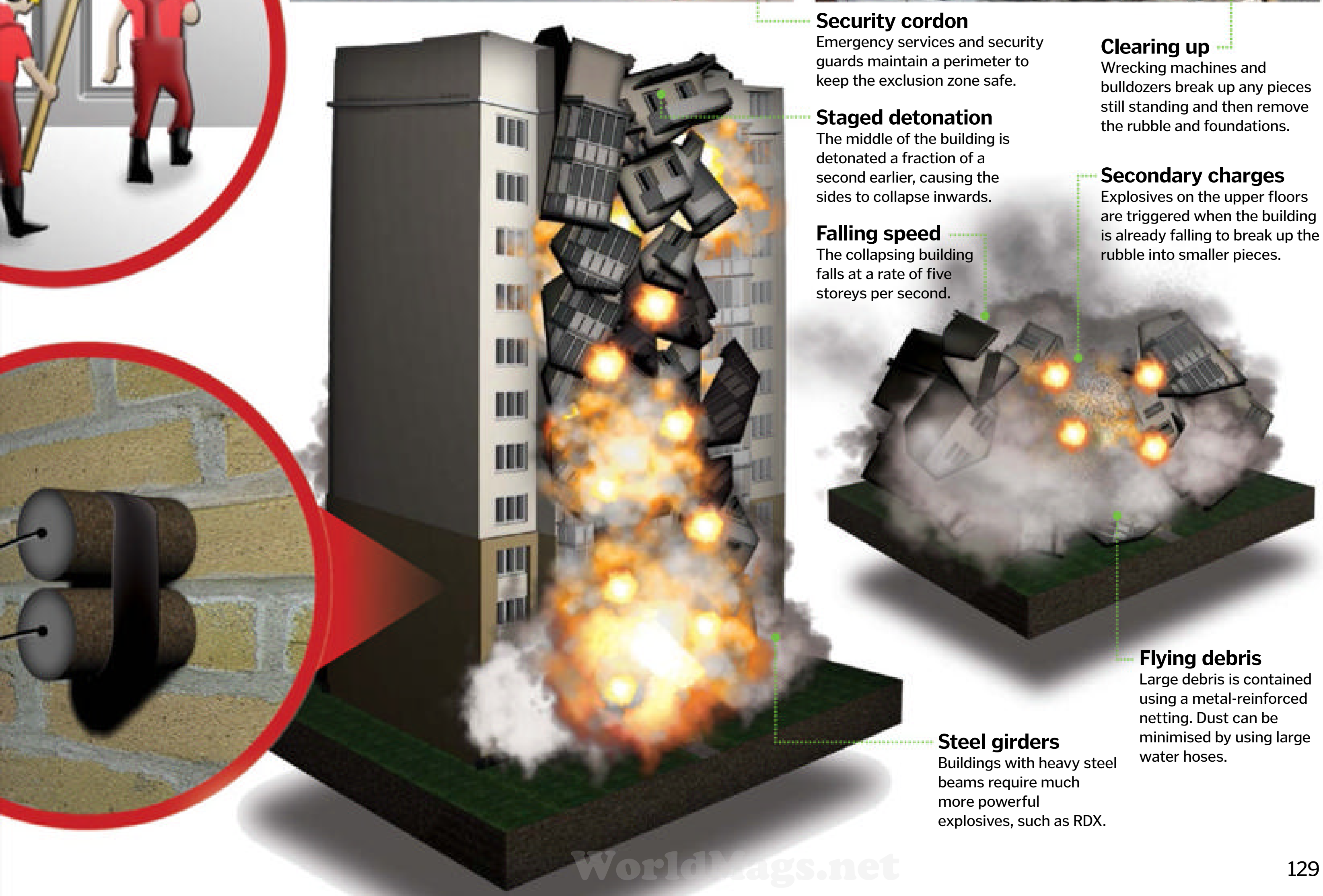
**DID YOU KNOW?** *The largest building demolished with explosives was the Sears Merchandise Center in Philadelphia*

residents are allowed back into their homes. "Then we lift the fencing and go off to the pub for a couple of pints," says Coleman. "After that we come back for typically about 12 weeks to munch up all the material and remove it from the site. Once it's all been taken away and we have exposed the slabs of the foundation, they are then broken out, processed and removed, and the void is backfilled and ready for the house builders to take over the site."

## A forensic operation

When a building catches fire or partially collapses, it can be so badly weakened that demolishing it is the only way to make it safe. If there are fatalities, the bodies must be carefully extricated. But if arson or negligence is suspected, demolition contractors must try to preserve any evidence for accident investigators. The building has to be peeled away one layer at a time without disturbing the layers below. Sometimes a building actually has to be strengthened before it is torn down to ensure it doesn't collapse in an uncontrolled way.

An exclusion zone with sentries is set up around the demolition site to ensure no one enters



**Security cordon**
Emergency services and security guards maintain a perimeter to keep the exclusion zone safe.

**Staged detonation**
The middle of the building is detonated a fraction of a second earlier, causing the sides to collapse inwards.

**Falling speed**
The collapsing building falls at a rate of five storeys per second.

**Clearing up**
Wrecking machines and bulldozers break up any pieces still standing and then remove the rubble and foundations.

**Secondary charges**
Explosives on the upper floors are triggered when the building is already falling to break up the rubble into smaller pieces.

**Flying debris**
Large debris is contained using a metal-reinforced netting. Dust can be minimised by using large water hoses.

**Steel girders**
Buildings with heavy steel beams require much more powerful explosives, such as RDX.

© Thinkstock; Alamy; Jorge Royan/www.royan.com.ar; Coleman & Company; Peters & Zabransky

# How do buildings rotate?

Explore the panoramic world of structures that like to get in a spin as we uncover the remarkable engineering that powers them

A new breed of architects has decided to make great views and sunbathed living rooms a permanent fixture by creating rotating houses. One of the first spinning homes was the Villa Girasole in Marcellise, Italy. This L-shaped residence sits on a circular base 44 metres (144 feet) in diameter, with three circular rails supporting it. Underneath these are 15 rollerskate-type wheels that run on grooves, all pushed along by two diesel motors attached to a central tower that pulls the building on a 360-degree rotation every nine hours and 20 minutes.

This design has formed the basis of many other rotating homes, such as the Everingham Rotating House in Australia, which was built in 2006 and works on much the same principle. It uses a 200-ton central bearing, 32 outrigger wheels to provide support, while movement is powered by two 500-watt electric motors. The Everingham house can complete a full circle in just half an hour, as well as using computer settings to place one of the wedge-shaped rooms facing toward the Sun.

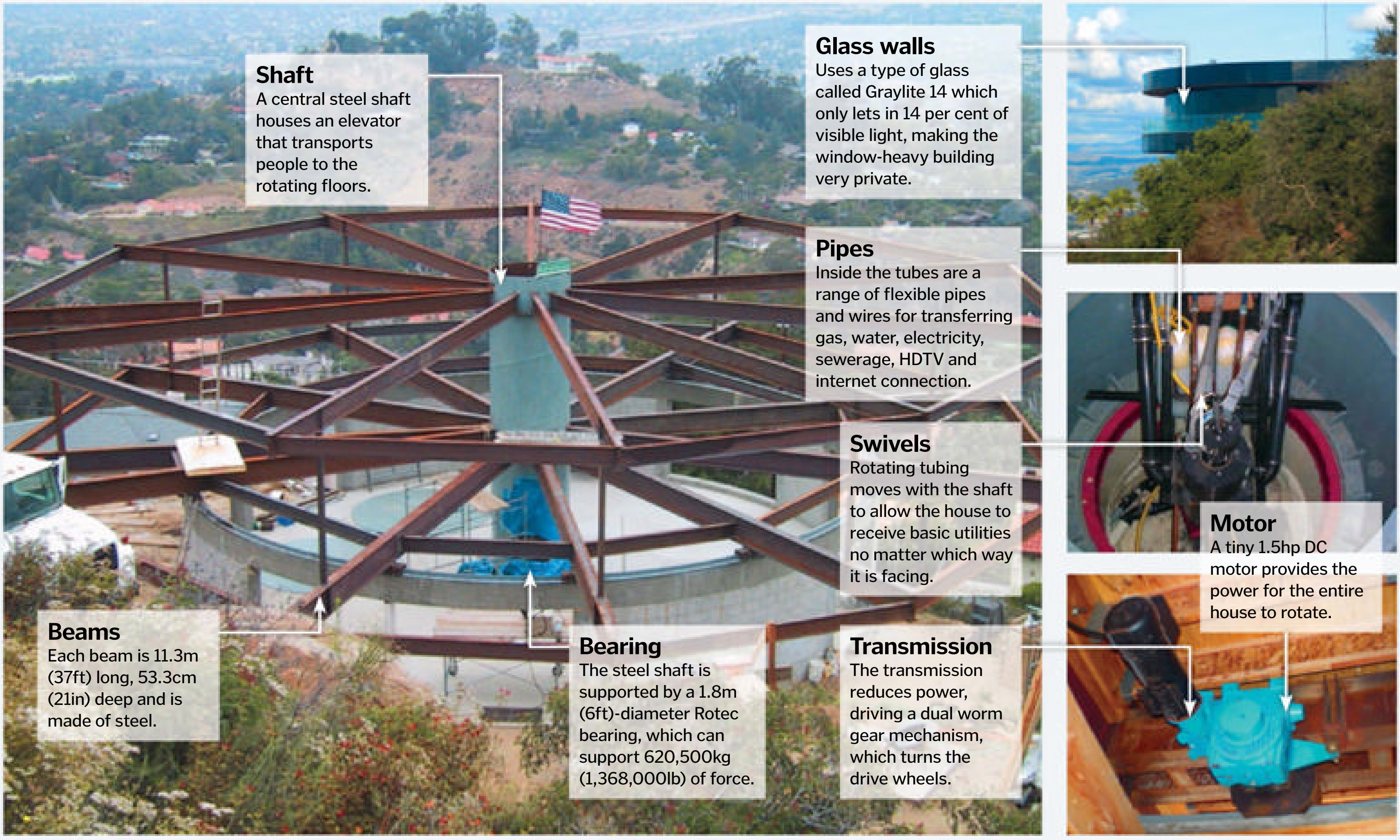
However, if you're looking for a truly eco-friendly rotating building, you can't ignore the Heliotrop in Freiburg, Germany. Powered by a 120-watt electric motor, it only consumes 20 kilowatt-hours per year due to the structure following the Sun to make maximum use of the dual-axis solar panels on its roof. The central column is made of Kerto Q boards from Finland, strengthened by epoxy resin-filled steel ties.

As with all cool structures, there always has to be someone who goes bigger and better and in this particular instance, that person is David Fisher of Dynamic Architecture.

Fisher has drawn out plans for an immense 80-storey building, of which each floor rotates independently. Its revolutionary design also has each floor built in a factory before being attached in complete form to the central tower on site. With developments like these, buildings that continually adapt to their environment could well be the future of architecture.

## House on the move

**What tech does a building need to do a full 360? Here we focus on the Rotating Home near San Diego, California**



**Shaft**
A central steel shaft houses an elevator that transports people to the rotating floors.

**Glass walls**
Uses a type of glass called Graylite 14 which only lets in 14 per cent of visible light, making the window-heavy building very private.

**Pipes**
Inside the tubes are a range of flexible pipes and wires for transferring gas, water, electricity, sewerage, HDTV and internet connection.

**Swivels**
Rotating tubing moves with the shaft to allow the house to receive basic utilities no matter which way it is facing.

**Motor**
A tiny 1.5hp DC motor provides the power for the entire house to rotate.

**Beams**
Each beam is 11.3m (37ft) long, 53.3cm (21in) deep and is made of steel.

**Bearing**
The steel shaft is supported by a 1.8m (6ft)-diameter Rotec bearing, which can support 620,500kg (1,368,000lb) of force.

**Transmission**
The transmission reduces power, driving a dual worm gear mechanism, which turns the drive wheels.

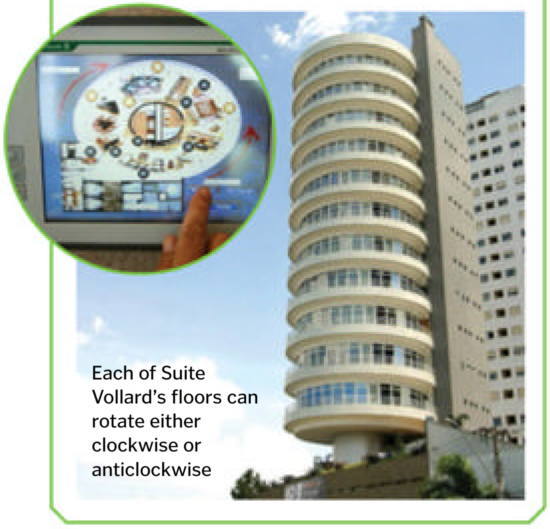
**DID YOU KNOW?** *The Sun rotates around the Earth at 15 degrees per hour, so that's the ideal house rotating speed for sunseekers*

## Suites apart

The Suite Vollard became the world's first entirely rotating building, with work on architect Bruno de Franco's building finishing in 2001.

Built in the Ecoville District of Curitiba in Brazil, the 15-storey building has 11 floors of residential apartments that enjoy a single revolution every hour. As with the plans for the Dynamic Skyscraper, all the apartments are built around a static central column made of concrete.

Amazingly a single rotation of the building needs only the same energy as a standard hairdryer. Each apartment is on a separate floor, which means that inhabitants are able to control the speed of their own rotation independently via a control panel in their home (see inset below).



Each of Suite Vollard's floors can rotate either clockwise or anticlockwise

## Pioneering spinner

One of the most famous early examples of a building in rotation is the BT Tower in London. This 190-metre (623-foot)-tall TV tower is topped by a restaurant that rotated from its opening in 1966 until it closed in 1980 over security fears.

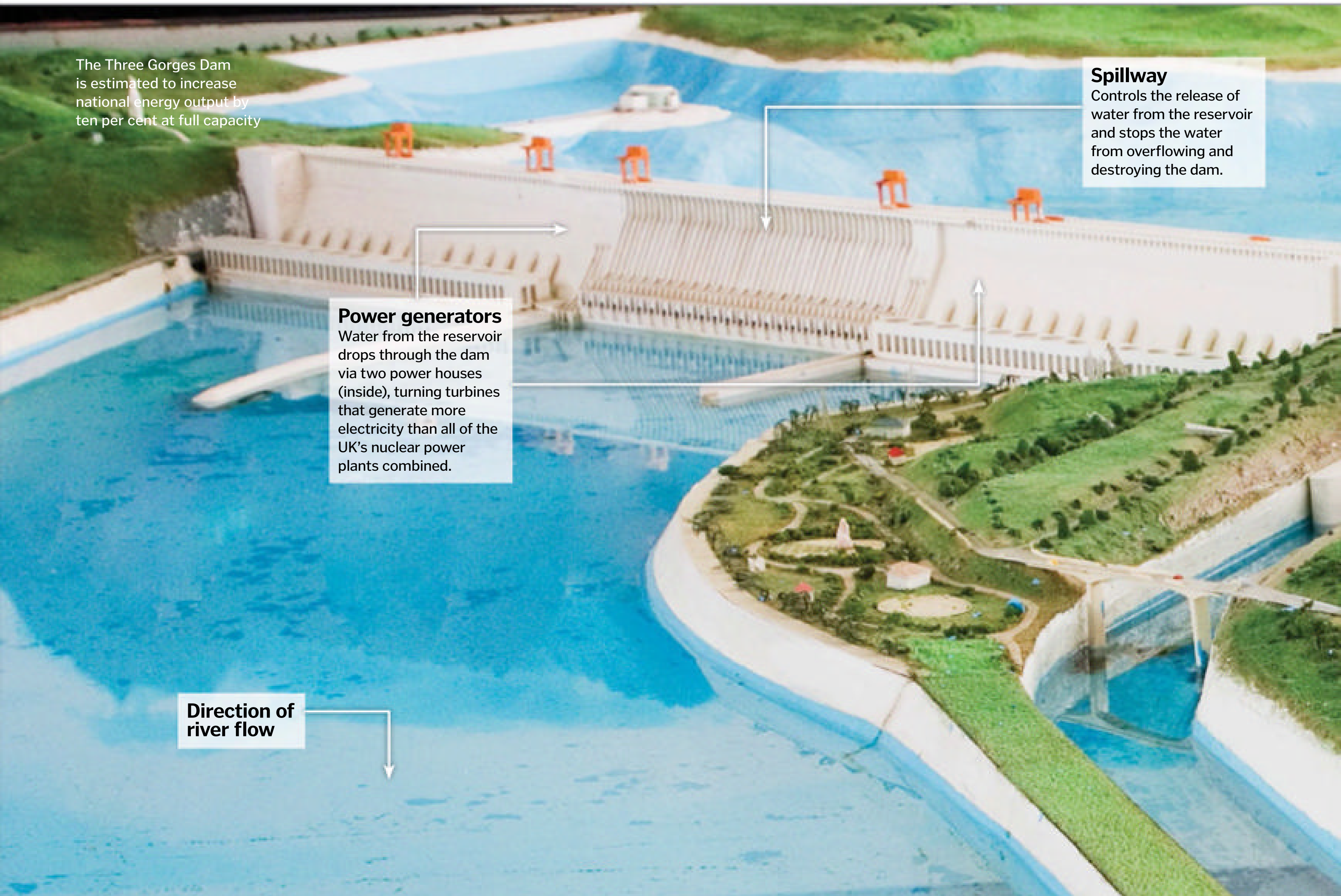
At the time, the tower was an engineering marvel, completing a full rotation every 22 and a half minutes, offering diners a panoramic view of the London skyline. The construction only required a two-horsepower electric motor to power the 0.27-kilometre (0.17-mile)-per-hour rotation. Allowing the top of the tower to move was a series of nylon bearings and rollers.

Despite being stationary today, the BT Tower remains one of London's most iconic landmarks and it has provided inspiration for many of the fully rotating buildings emerging today.

The Heliotrop in Freiburg, Germany, actually uses rotation to save energy, via solar panels on the roof

Left: The Space Needle in Seattle, USA, has an observation deck and a rotating restaurant at the top

© Alamy; Corbis; Rolf Disch Solar Architecture, Freiburg, Germany; RotatingHome.com



The Three Gorges Dam is estimated to increase national energy output by ten per cent at full capacity

**Spillway**
Controls the release of water from the reservoir and stops the water from overflowing and destroying the dam.

**Power generators**
Water from the reservoir drops through the dam via two power houses (inside), turning turbines that generate more electricity than all of the UK's nuclear power plants combined.

**Direction of river flow**

# Dam engineering

## How these structures are built to withstand immense natural forces

Building any dam presents a unique engineering challenge, since no landscape or water system is exactly the same. One of the best sites to build a dam is in a narrow river valley with steep rocky sides strong enough to support the structure. The first step is to divert the water around the area you want to build, and for large dams in rocky environments, explosives are used to blast a new channel through the terrain. A temporary barrier is needed to keep water out of the area normally submerged.

Traditionally, a wet concrete mixture is poured into moulds, hardening to form the shape of the intended dam. Gravity dams, meanwhile, like the Three Gorges Dam in China have walls with steep slopes, and rely solely on their immense weight to hold the water back. Arch dams, like the Hoover Dam in the USA, use their curved shape to balance out the pressure. Buttress dams get their strength from concrete pillars lined along the face of the structure, and embankment dams slope gradually and are made from compacted earth. The world's largest dams weigh millions of tons, making strong foundations that reach deep below the original ground level essential.

## History of dams

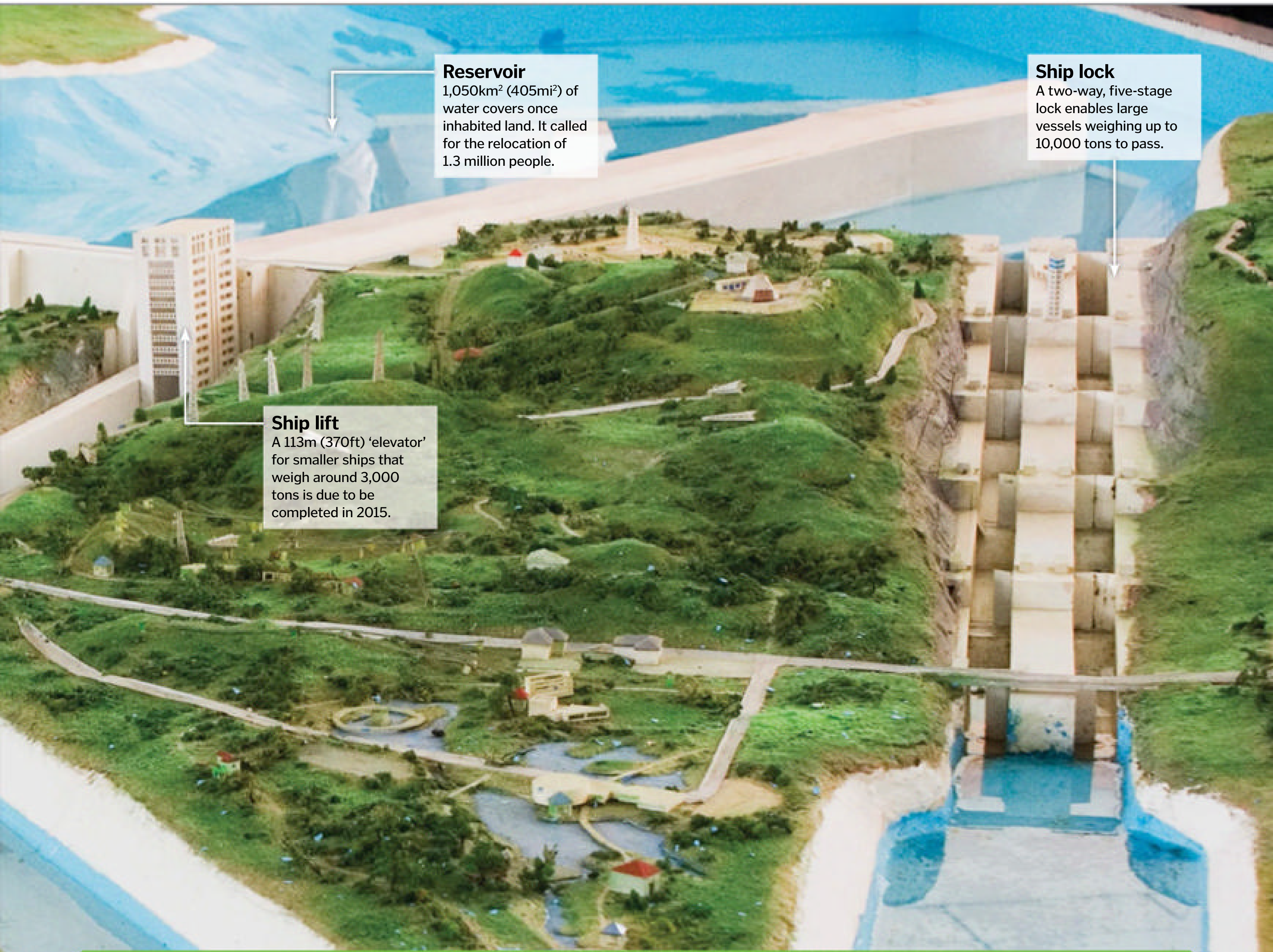
The first dams were simple gravity dams made of masonry. The Ancient Egyptians were the first to realise dams could alleviate floods. In 2650 BCE, work began on a large embankment dam called Sadd el-Kafara. At 110 metres (360 feet) long and 14 metres (46 feet) tall, it would have been the largest in the world, but a flood destroyed it before it was finished. Marduk Dam in Mesopotamia, from circa 2000 BCE, was the first embankment dam, built to prevent flooding and to irrigate crops.

The Romans embraced dam building, using them to transport, store and distribute water in new ways – and at least two Roman dams are still used today. Modern dam construction took off in the mid-19th century as knowledge of structural theory and materials science came to light.

## THE STATS
### THREE GORGES

WEIGHT 65mn tons
HEIGHT 185m
STARTED OPERATING 2003
BREADTH 2km
BUILD TIME 17yrs
OUTPUT 22,500MW

**DID YOU KNOW?** *Building the Three Gorges Dam raised so much water that the Earth's rotation slowed slightly*



**Reservoir**
1,050km$^2$ (405mi$^2$) of water covers once inhabited land. It called for the relocation of 1.3 million people.

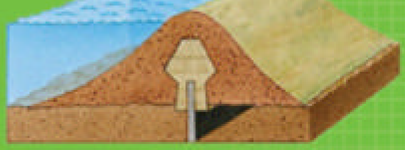
**Ship lock**
A two-way, five-stage lock enables large vessels weighing up to 10,000 tons to pass.

**Ship lift**
A 113m (370ft) 'elevator' for smaller ships that weigh around 3,000 tons is due to be completed in 2015.

## Three major types of dam

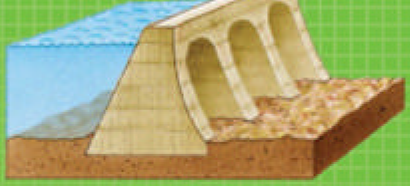
### Embankment dam

Made from a bank of earth, these dams rely on their intense weight and sloped shape to hold the water back. There may be an impervious layer of concrete, plastic or other material on the upstream face if the particle sizes in the earth are big enough for water to seep through. Earth-filled dams can be made completely from one type of material, but may need a layer that collects and drains seep-water to ensure the structure stays intact.



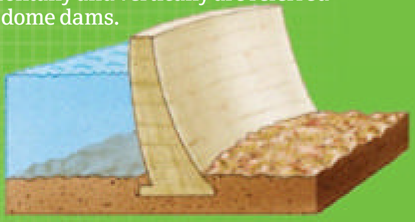
### Buttress dam

Buttress dams are used when the surrounding rock is not strong enough to provide a solid foundation. A series of solid concrete buttresses lined along the downstream face of the dam provide the strength needed to hold it in place. Buttresses add weight to the structure, pushing towards the ground and anchoring the dam even further. Since most of the support comes from the buttresses, the dam wall can either be flat or curved.



### Arch dam

Best for narrow rocky ravines with steep walls strong enough to support the structure, these are solid concrete structures that curve upstream, forming an arch. The pressure from the water is distributed evenly for structural integrity, similar to an arch bridge. The weight of the dam pushes it into the ground, helping to reinforce it. Examples that are double-curved horizontally and vertically are referred to as dome dams.



© SPL; Thinkstock

# How a car is made

## We travel to Germany to witness cars being born on the European production line

It's 8.30am on a cold September morning in Cologne as we shuffle our way into the European headquarters of the international motoring giant Ford. Along with a select few from the media, we are the first-ever members of the press to have been invited for a sneak peak behind the factory gates. The statistics say a new Ford Fiesta rolls off the production line every 86 seconds, so let's begin the tour to see how.

It starts at the body shop where a robot will attach the car door to the vehicle. Laser lines are used to ensure a precise fit. The body of the car is then cleaned in the body washer to prepare for the paint job. More robot arms then coat the car in its new colour and the body then goes into the wax oven before heading to the assembly plant. Next comes the 'marriage' – the most important part of automobile production. This is where the engine is united with the body and the wheels are fixed.

Speaking of engines, 26 million of them have been made at the factory since it opened its doors on 12 February 1962. Our tour leader and Plant Quality Manager Axel Jaedicke explained that this was enough to make a line from Los Angeles and back! It was fascinating to see how an engine is carefully made from scratch, but most impressive of all was the skill in which it was put together so expertly and efficiently.

The vast hangar ran like clockwork and the whole process to build an entire engine takes a very speedy four hours and 12 minutes. To maintain the high quality levels expected, one in every 5,000 engines enters into a "teardown audit" where engineers analyse and measure the completed machine.

Ford also considers the efficiency of the production process as well as the engine itself. ▶

# The three stages of assembly

**How the production line is divided up**

**1 Trim line**

The first line attaches the smaller parts of the car such as the pedals, horn, seat belts, electrical switches, wipers and shock absorbers.

4088
EISENMANN

**2 Chassis line**

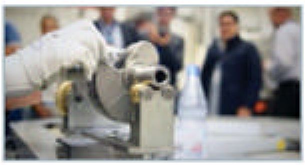
As the name suggests, this line deals with larger bits of kit such as axles, fuel pipes, exhausts, tyres and bumpers.

Ex
EISENMANN

**3 Final assembly line**

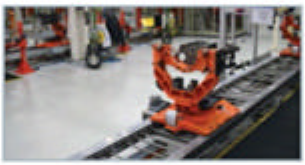
The last few essential parts are brought on board on this line, like glove boxes, sun visors, parking brakes and the license plate lamp.

## Engine timeline



Here, the cylinder blocks queue up to be automatically machined in the state-of-the-art CNC machining centres.

A close-up view of a finished crankshaft being inspected for any visual flaws.



The cylinder block is bolted to a fixture on the assembly platen. The engine can now be rotated providing access to all sides of as it moves through the line.

The front view of a fully assembled engine, prior to its shipment to the vehicle assembly plant.

A side-elevation view of the intake side of the fully built and assembled engine.

It uses a technique called Minimum Quantity Lubrication (MQL), which drastically reduces the amount of coolant and lubricant required to keep the factory's cutting tools working properly, saving both resources and power.

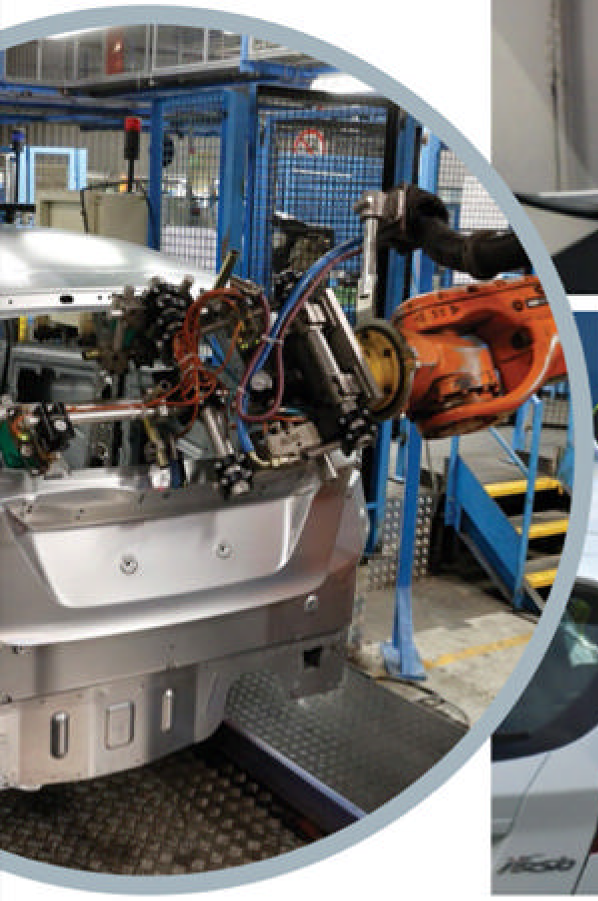
The EcoBoost has the lowest fuel consumption levels in its class and the majority of its main rivals use four-cylinder versions. Happily for petrolheads, Ford claims there is no loss of sound quality despite having one less cylinder than many other cars in its power range. Overall it's a pretty nifty piece of kit, but what's an engine without a car to put it in?

Before the car is born, between 60 and 80 potential designs are sketched and eight clay models are made to fine-tune the final product. At the beginning of the line, the car is an empty, hollow grey shell, a far cry from the sleek supermini it will end up being. A

**The rigorous testing the supermini is put through**

**Power run**
A test driver positions the Fiesta on a rolling road and will try to max out the car's power as it is held in place but allowed to accelerate. This test measures the torque of the wheels and the power of the flywheel to see if they are reaching the required level.

**Water immersion**
After the power is tested, the structural integrity of the vehicle must be assessed. Water is sprayed powerfully from every direction so any gap will be exposed. HIW sat shotgun during the test, hoping the car was leak free!



30
8
Cobblestone

**Bumpy road**
The last test HIW witnessed was to decide whether the suspension was up to scratch. Traversing over all manner of rough and uneven roads, the Fiesta was put through its paces in order to make sure it could handle all surfaces.

## THE STATS
### BUILDING THE PERFECT FIESTA

**310** PANELS WELDED INTO THE CAR IN ASSEMBLY

**29** SIZE OF THE FACTORY IN FOOTBALL PITCHES

**3.5** HOURS AN ENGINE SPENDS ON THE PRODUCTION LINE

**350,000** ECOBOOST ENGINES BUILT PER YEAR

**£106 ($169) MILLION** INVESTED IN THE ECOBOOST FACILITY

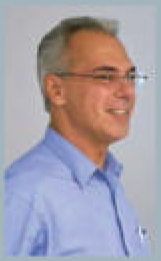
**72** COUNTRIES THE FIESTA IS AVAILABLE IN

**DID YOU KNOW?** *EcoBoost turbochargers spin at over twice the rpm of the ones powering F1 engines – over 4,000 times per second!*

HIW writer Jack Griffiths (second from left) on tour at the Ford factory

A fully assembled and ready-to-drive Ford Fiesta, fresh off the production line

## Focus on quality
### Interview with Harald Stehling, the head of the factory's quality control



**What is the role of Ford Cologne in Ford's global and European operations?**
Cologne is the lead global Ford Fiesta Plant.

**What products does the factory produce and what is its 'flagship' product?**
At the Cologne plant, the 1.0-litre EcoBoost engine and the Ford Fiesta are produced. These are also the 'flagship' products.

**Is a whole car created here or just part of the process?**
At the Cologne plant it is stamping, body, paint, trim and final assembly, and the supplier park is connected to the production line as well. Most parts of the vehicle are created in Cologne.

**What parts of the car are handmade and what is machine made? Why is this?**
Parts are machine made, assembly mostly handmade. The reason for this is the high volume and cost for parts. The assembly is rather difficult to automate (such as wheel automation).

**Does the Cologne plant have any competition with other factories?**
Yes, in all metrics you can imagine, like safety, quality, volume and harbour report.

concrete jungle of welding machines, hydraulic robot arms and conveyer belts, the building is a hive of activity. On each vehicle 310 panels are welded together along with 1.2 kilometres (0.75 miles) of wiring. This is done at temperatures of up to 1,400 degrees Celsius (2,552 degrees Fahrenheit) so it was lucky we were behind protective glass when we got close!

Although the process looks like it never alters, 11,400 variations of the Fiesta are made between the three-door, five-door, ST and van models. The Fiesta's assembly is completed by a full immersion into an electro-coat fluid to add a corrosion-resistant layer, and the addition of waterproofing and vibration reducing sealer. But this is not the end of the journey; last but not least are Ford's rigorous testing procedures.

Each model will undergo 40 real-world crash tests, experience temperatures from -40 degrees Celsius (-40 degrees Fahrenheit) to 82 degrees Celsius (180 degrees Fahrenheit) and 130 hours of wind-tunnel testing at speeds of 130 kilometres (81 miles) per hour. HIW had a go at the water test – where torrential rainfall was imitated – and the suspension test, where some bumpy surfaces had to be navigated.

The Fiesta passed both with flying colours as the interior was left completely dry and little discomfort was felt on the rocky road. In addition to the physical exam, Ford employees utilise the power of the 3D Cave Automatic Virtual Environment (CAVE) to perform 5,000 virtual crash simulations. This system allows intricate details to be tested and improved upon without the need for more twisted metal and fuel consumption.

From the original concept ideas to the final touches on the assembly line, the life of a car is an extensive one even before it hits the showroom. It's fascinating how years in the making boils down to 86 seconds on the production line.

## The future of the assembly line

It seems as if all the new technology in the world today goes through Google in some way and now assembly lines can be added to that list. In partnership with international robotics company Foxconn, the focus is on increased automation and robotic use within the factories, taking the strain off manual labour. Tesla is another firm inventing new assembly robots. However, Tesla's stance is that less is more as it is creating robots suited to more than one function, for example able to put on wheels as well as attaching a door. This will hopefully have the dual effect of lowering costs while increasing efficiency at the same time.

© Ford; Tesla

# Harnessing tidal power

How do these marine power plants turn the sea's motion into electricity?

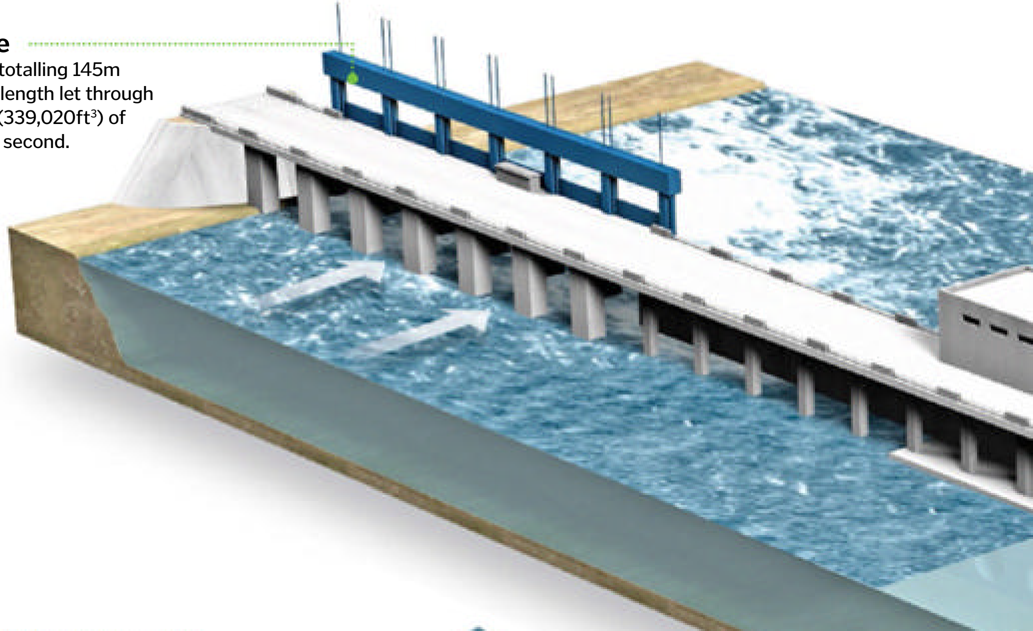
Tidal power plants use the rise and fall of tides to produce electricity. One way to harness tidal power is to build a barrage – a dam with gates that regulate water flow – across an estuary. When the gates are open, water flows through turbines, generating electricity. Water flows through at high tide, filling up the river or estuary behind it. The gates are then closed until low tide, creating a lower water level on the sea-facing side.

Next, the gates are opened, allowing the water to flow back out towards the sea. One downside is that electricity can only be generated for around ten hours per day – at high tide and low tide. However, tides are very predictable, making tidal power considerably more reliable than, say, solar or wind energy.

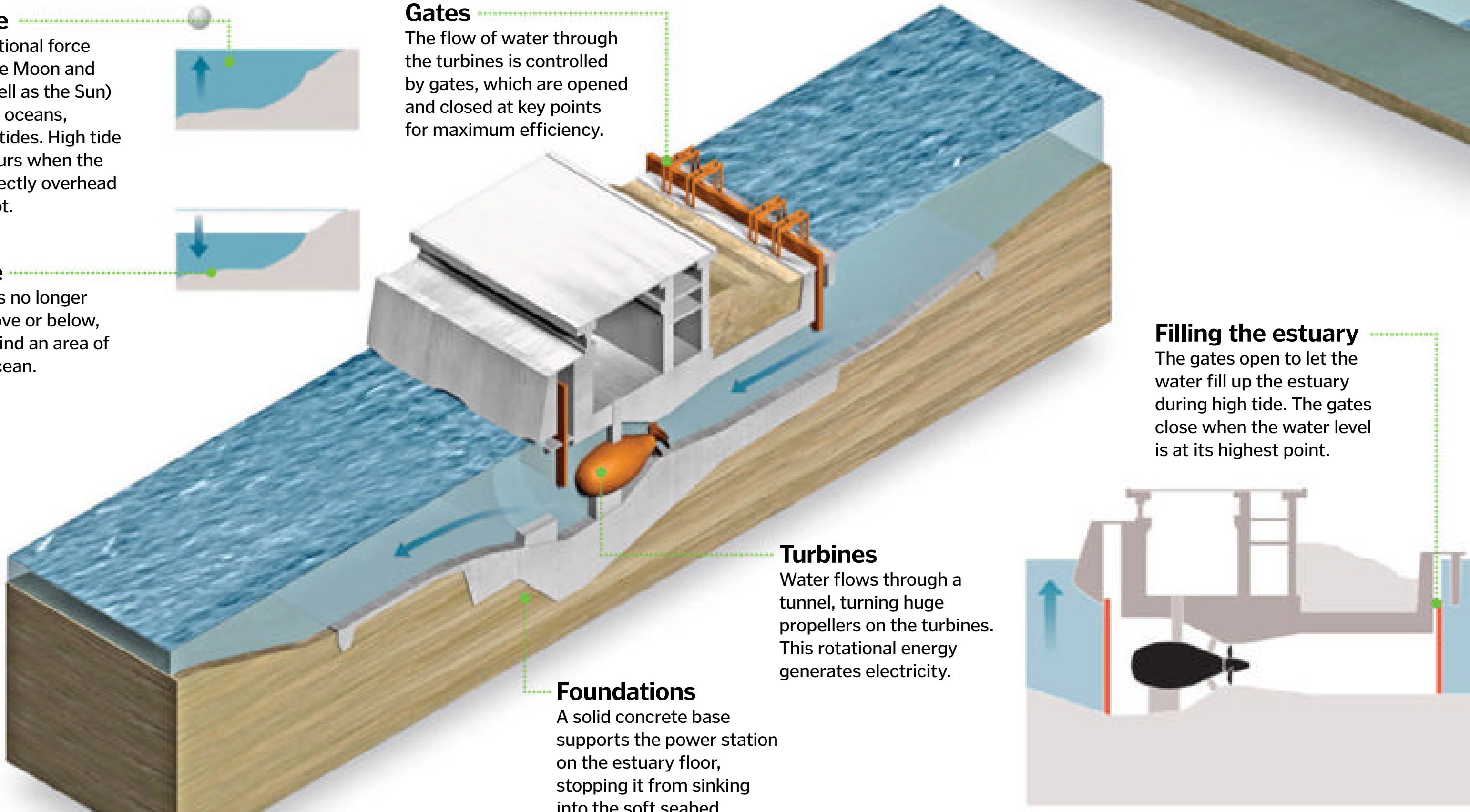
One of the negatives is that building tidal power plants often requires emptying parts of an estuary, which can have devastating consequences for local marine life.

## Turning tides into electricity

**Using the Rance tidal power station as a case study, we see how these amazing facilities work**



**Barrage**
Six gates totalling 145m (476ft) in length let through 9,600m³ (339,020ft³) of water per second.



**High tide**
The gravitational force between the Moon and Earth (as well as the Sun) pulls on the oceans, generating tides. High tide usually occurs when the Moon is directly overhead or underfoot.

**Low tide**
The Moon is no longer directly above or below, leaving behind an area of low-level ocean.

**Gates**
The flow of water through the turbines is controlled by gates, which are opened and closed at key points for maximum efficiency.

**Filling the estuary**
The gates open to let the water fill up the estuary during high tide. The gates close when the water level is at its highest point.

**Turbines**
Water flows through a tunnel, turning huge propellers on the turbines. This rotational energy generates electricity.

**Foundations**
A solid concrete base supports the power station on the estuary floor, stopping it from sinking into the soft seabed.

**RECORD BREAKERS**

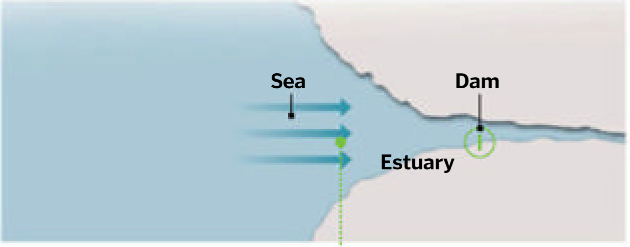
**SIHWA LAKE**

# 254MW

## BIGGEST TIDAL POWER STATION

Sihwa Lake Tidal Power Station, located in South Korea, was finished in 2011 and can pump out 254 megawatts of electricity – enough to power 50,000 homes.

**DID YOU KNOW?** *Tidal power is the only technology to work from gravitational energy in the Earth/Moon orbital system*

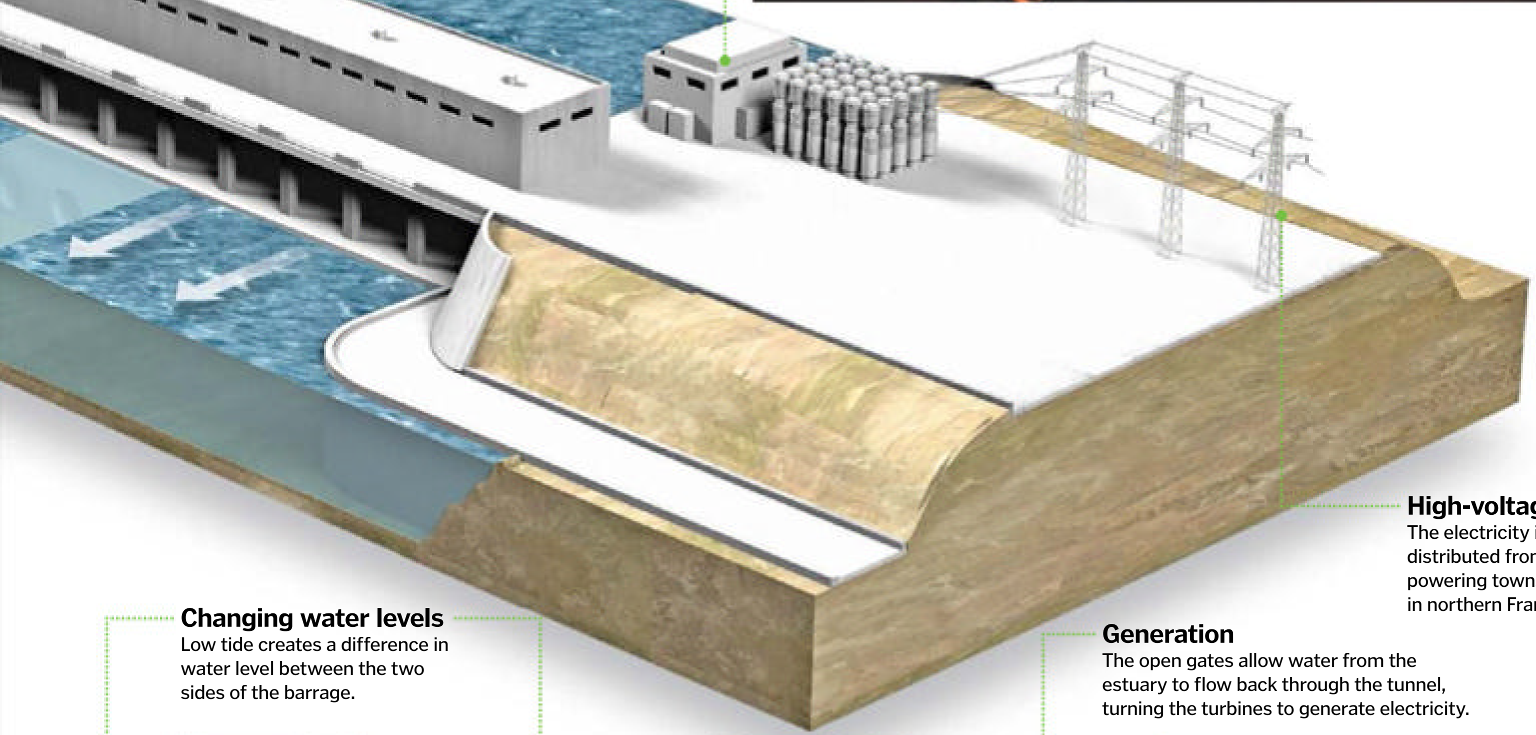


**Location**
The power station sits in the La Rance estuary, where water flows into the English Channel.

The AK1000 is one of the most powerful single axis tidal turbines on Earth

**Turbines**
Water flows through 24 turbines, transferring kinetic energy from the water into electricity.

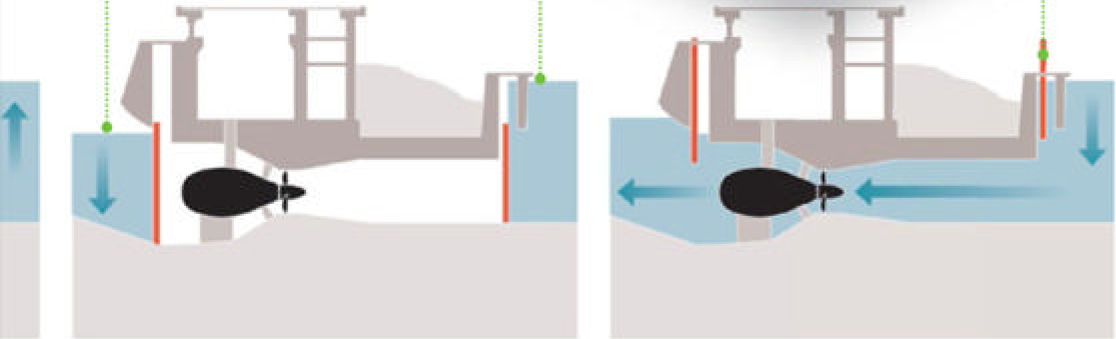
**Electrical substation**
Voltage is stepped up from low to high to make it suitable for the national grid.



**High-voltage grid**
The electricity is distributed from here, powering towns and cities in northern France.

**Changing water levels**
Low tide creates a difference in water level between the two sides of the barrage.

**Generation**
The open gates allow water from the estuary to flow back through the tunnel, turning the turbines to generate electricity.



## Rance: the first tidal power station

The Rance Tidal Power Station, situated on the Rance River estuary in France, was built in 1966. The site was chosen for its extreme tide levels – an average of eight metres (26 feet) difference between high and low tide. Two temporary dams were made to allow drainage of the construction site, protecting it from the sea. It is still the second largest in the world today, the biggest being the Sihwa power station in South Korea.

© Solo Images; Alamy

# Inside a pyrometer

The tool that's tough enough to measure superhot objects

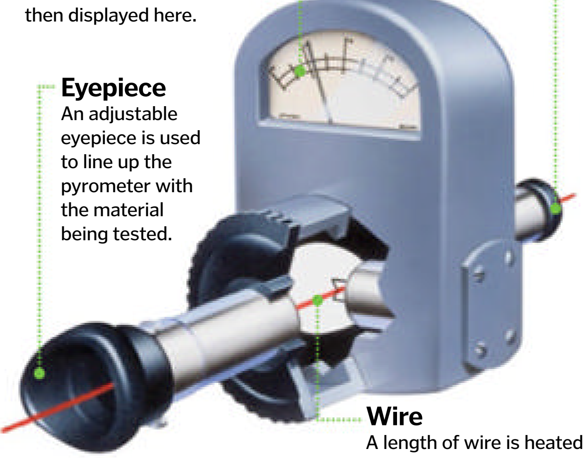
To measure the temperature of objects hot enough to melt more traditional thermometers, a pyrometer is often used. These specialist thermometers use the electromagnetic radiation released by extremely hot objects to determine their temperature from a distance.

As objects heat up they release infrared and visible light, which can be used to determine their temperature. An optical pyrometer contains a metal wire, which can be heated using a variable electrical current; as the wire is heated, it changes colour. By matching the colour of the wire to the colour of the object being tested, an approximate temperature can be deduced.

A more accurate reading is obtained by focusing the electromagnetic radiation on temperature-sensitive electrical components. The components then produce a variable current, depending on the heat level.

## Optical pyrometer up close

**This simple piece of kit can safely calculate the temperature of scorching-hot objects**



**Readout**
The temperature of the test object is determined using the current required to heat the wire to the same colour and then displayed here.

**Lenses**
The electromagnetic radiation released by the sample is focused using a series of lenses.

**Eyepiece**
An adjustable eyepiece is used to line up the pyrometer with the material being tested.

**Wire**
A length of wire is heated until its colour matches that of the test material.

## Origins in the pottery trade

Founder of the Wedgwood pottery company, Josiah Wedgwood, invented the pyrometer in the 18th century to measure the temperature of his kilns. Clay changes colour depending on the temperature at which it is fired. Wedgwood made a series of pieces of clay, fired at known temperatures, ranging in colour from buff (low temperature) to red (high temperature).

Using these as a guide, he was then able to determine the temperature of the kiln by comparing the colour of the clay to his predetermined reference scale. Wedgwood was elected to the Royal Society in 1783 in recognition of his scientific achievements.

# Popcorn machines

Popcorn makers rapidly turn hard corn kernels into fluffy popcorn, but how do they do it?

Dried corn kernels contain about 12-15 per cent water, which turns to vapour when heated. As the steam expands, pressure builds up inside the tough outer shell of the kernel until eventually the corn bursts. The starch granules inside the kernel become gelatinous when heated and expand outwards to form a network of jelly-like bubbles. As they cool, they solidify to leave the puffy, white snack we are all familiar with.

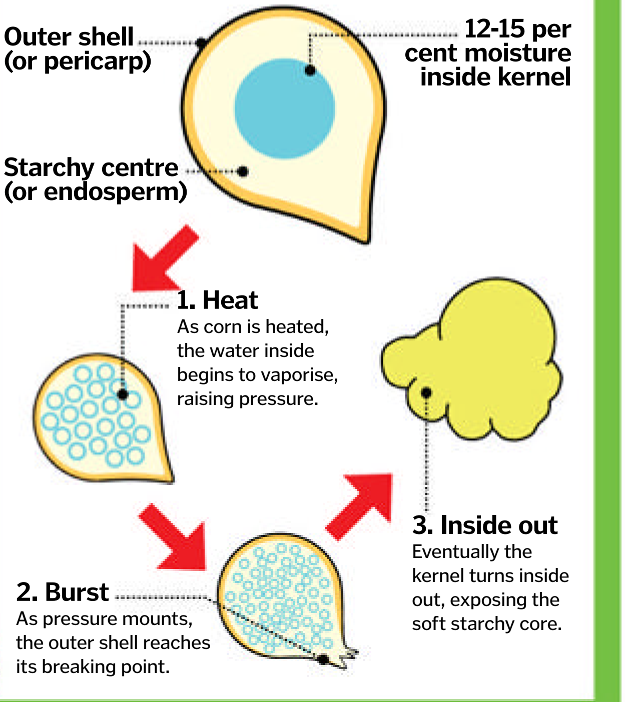
Traditionally, popcorn makers use hot oil to convert the internal moisture of the kernels to steam, but hot air can also be used. Within the main chamber of a popcorn maker there is an electric heating element, which warms the oil or air. The kernels are placed inside the chamber and mixed continually by a fan or rotating blade to prevent them from burning before they reach the temperature required to pop.

The lid of these devices is quite light and often on a hinge, so that as the popped kernels build up inside the chamber the lid lifts, letting you know the popcorn is ready.

When put under a little heat, corn can't handle the pressure so essentially bursts, turning inside out

## Popping corn in action

**See, step by step, how this movie snack is made**



**Outer shell (or pericarp)**

**12-15 per cent moisture inside kernel**

**Starchy centre (or endosperm)**

**1. Heat**
As corn is heated, the water inside begins to vaporise, raising pressure.

**2. Burst**
As pressure mounts, the outer shell reaches its breaking point.

**3. Inside out**
Eventually the kernel turns inside out, exposing the soft starchy core.

© Thinkstock; Alamy

# Swimming pool designs

Take the plunge to see the hidden technology that keeps pools safe and clean

At first glance, a swimming pool might just look like a huge basin filled with water, but hidden beneath the surface is a surprising amount of technology.

The water is constantly circulated through a filtration system, passing out of the main pool through two or more drains at the bottom as well as 'skimmer' drains located around the sides. The main drains collect any debris that sinks to the bottom of the pool, while the skimmer drains take in small amounts of surface water in order to sift out any floating contamination, like hair, bugs and leaves.

The water is drawn through the system by an electric motor, which drives a pump. As the water flows towards the pump a sieve removes any large debris. The water then enters the filtration system, which contains high-grade sand in a vertical column. Gravity pulls the water through the sand and small particulates become trapped in the tiny grains, before the cleaned water passes back out into the pool.

The pump system generates powerful suction, which could create dangerous vortices; the main drains have anti-vortex covers to prevent this. Using multiple drainage points also minimises the risk of people being trapped by suction; if one drain becomes blocked, the pump draws water from the others, decreasing the suction and dislodging the blockage.

Heaters are often included in the pump system to warm the water as it passes through; a thermostat switches the heater on and off to maintain a comfortable temperature.

## Focus on chlorine

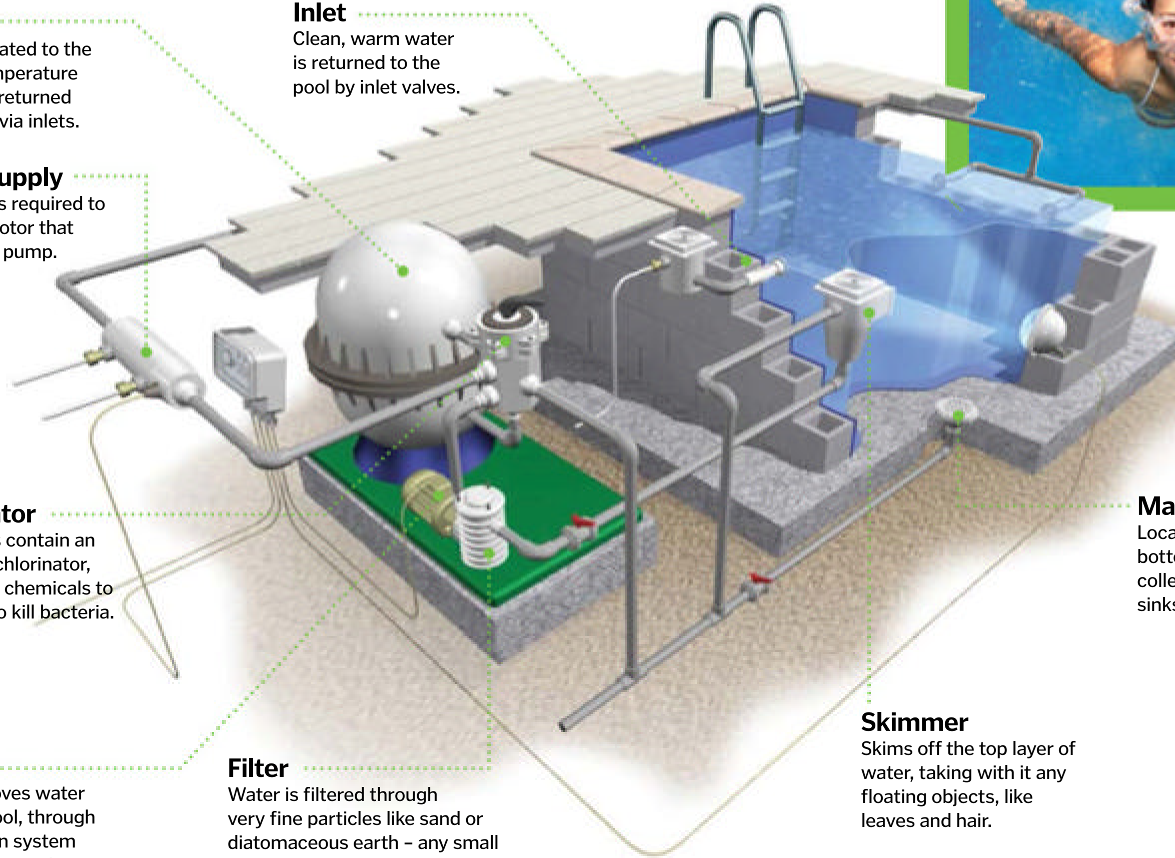
The majority of the technology in a swimming pool is designed to keep it free of debris and to maintain water temperature. But microscopic organisms thrive in warm, still water, so to keep the pool safe, chemical sterilisation is often used.

Chlorine – either in the form of calcium hypochlorite or sodium hypochlorite – is added as a disinfectant. It reacts with water to form hypochlorous acid, which interferes with bacterial cell walls, DNA and enzymes.

Hypochlorous acid breaks down when exposed to UV light though, which is particularly problematic in outdoor swimming pools. Often a stabilising agent is added to keep the chlorine in a usable form for longer. Hypochlorous acid also reacts with ammonia (found in urine) to form compounds called chloramines, which smell bad and can irritate the eyes. A careful balance of chlorine and stabilisers must be maintained to keep the pool safe yet comfortable to swim in.

## Beneath the surface...

**The underground plumbing of a swimming pool filtration system**



**Heater**
Water is heated to the desired temperature before it is returned to the pool via inlets.

**Inlet**
Clean, warm water is returned to the pool by inlet valves.

**Power supply**
Electricity is required to drive the motor that powers the pump.

**Chlorinator**
Many pools contain an automatic chlorinator, which adds chemicals to the water to kill bacteria.

**Main drain**
Located at the very bottom of the pool, it collects any debris that sinks to the bottom.

**Skimmer**
Skims off the top layer of water, taking with it any floating objects, like leaves and hair.

**Pump**
A pump moves water from the pool, through the filtration system and back out again.

**Filter**
Water is filtered through very fine particles like sand or diatomaceous earth – any small contaminants become trapped.

© Thinkstock

# Ivanpah Solar Power Facility

## See how the most advanced solar-powered energy generation site produces electricity

The Ivanpah Solar Power Facility is a brand-new solar thermal power site located in the Mojave Desert in western USA. The facility, which consists of three state-of-the-art thermal power plants lies 64 kilometres (40 miles) south-west of Las Vegas and has a total capacity of 392 megawatts, making it one of the largest of its kind in the world.

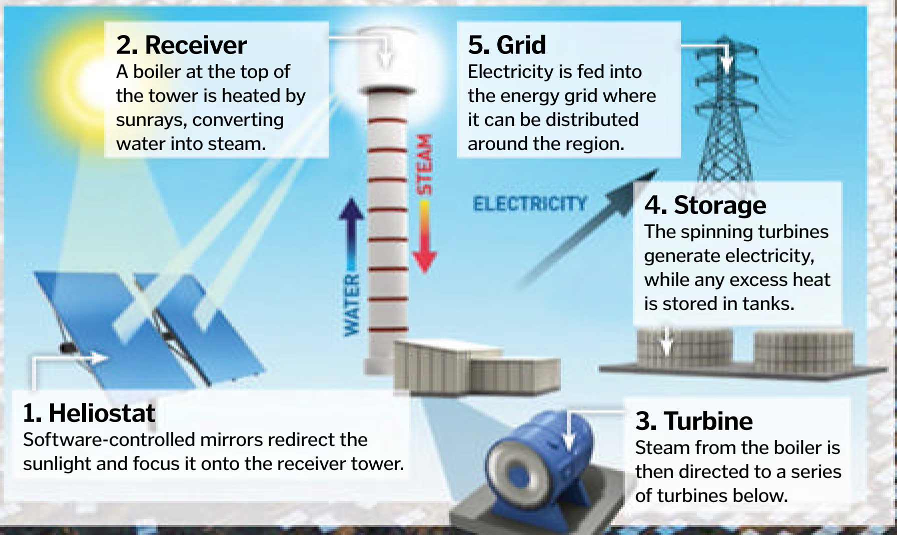
Ivanpah achieves this energy with over 170,000 Sun-tracking heliostats (mirrored panels), which receive a vast quantity of direct sunlight over the 1,415-hectare (3,500-acre) site and redirect it onto steam-producing thermal boilers mounted on top of three receiver towers. This steam is then used directly to power electricity-producing turbines (see 'Ivanpah step-by-step' below to follow the process).

Construction of the Ivanpah project began in October 2010 and it formally opened in February 2014, with the site set to contribute to California's existing electricity grid.

However, the project has been seen by some environmentalist organisations as controversial due to its construction over an established ecosystem. In particular over 200 desert tortoises needed to be relocated during the build, with a cost of $55,000 per tortoise needed for the move.

## Ivanpah step-by-step

**From heliostat to energy grid, how does Ivanpah deliver so much power?**



**2. Receiver**
A boiler at the top of the tower is heated by sunrays, converting water into steam.

**5. Grid**
Electricity is fed into the energy grid where it can be distributed around the region.

**4. Storage**
The spinning turbines generate electricity, while any excess heat is stored in tanks.

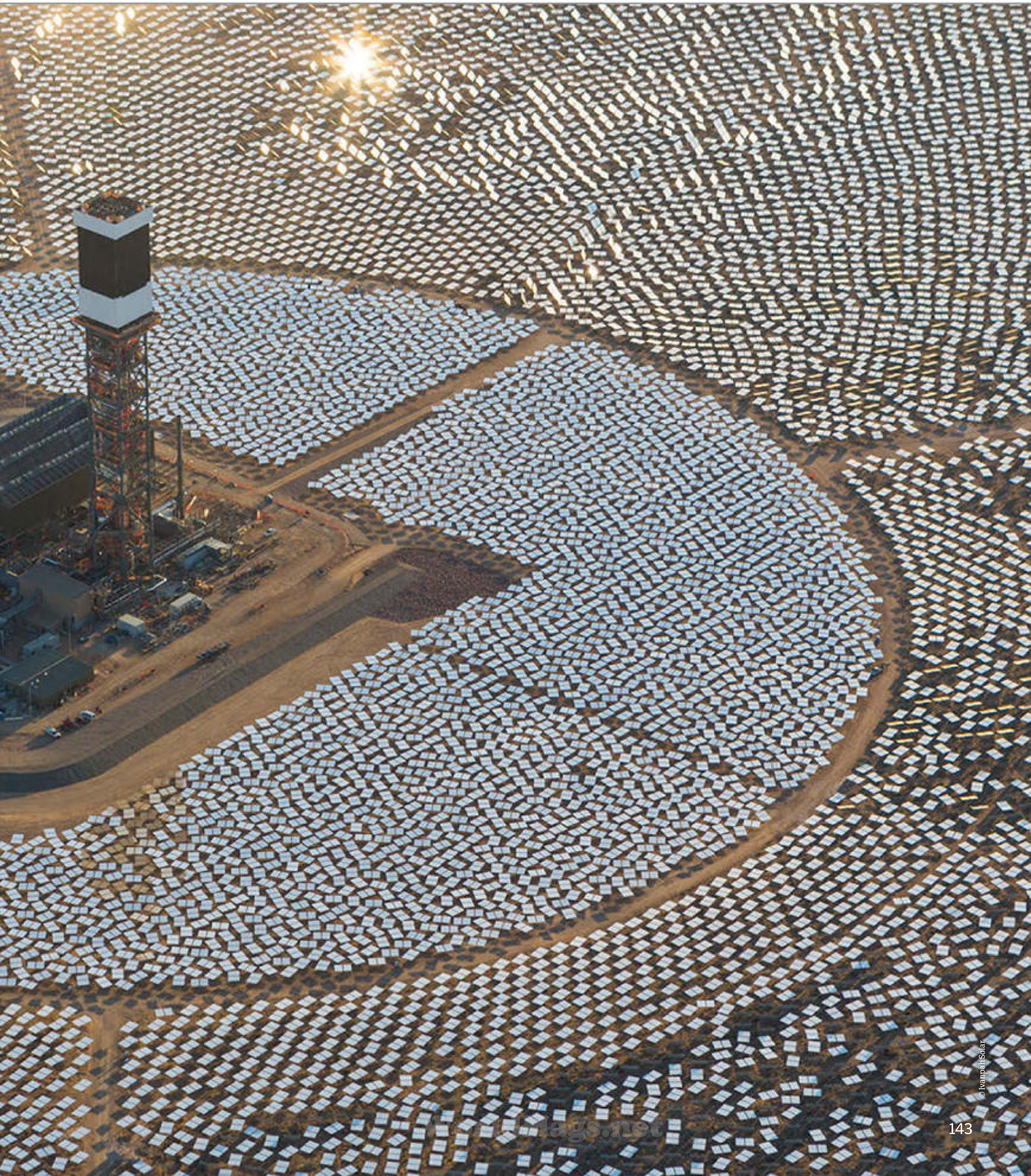
**1. Heliostat**
Software-controlled mirrors redirect the sunlight and focus it onto the receiver tower.

**3. Turbine**
Steam from the boiler is then directed to a series of turbines below.

## THE STATS
**IVANPAH FACILITY**

| | | | | | |
|---|---|---|---|---|---|
| HELIOSTATS | 173,500 | LAND AREA | 14.2km² | REDUCTION IN $CO_2$ (TONS/YR) | 400,000 |
| MAXIMUM CAPACITY | 392MW | ANNUAL POWER GENERATION | 1,079,232MWh | THERMAL PLANTS | 3 |

**DID YOU KNOW?** *The Ivanpah Solar Power Facility cost in the region of £1.4 billion ($2.2 billion) to build*



© Ivanpah Solar

# Secrets of the synchrotron

## Find out how the UK's largest laboratory can accelerate electrons to nearly the speed of light

Electromagnetic (EM) radiation is incredibly useful. It enables us to transmit music wirelessly over large distances, cook food in our microwaves and see the world around us in vivid detail. However, now more than ever, electromagnetic radiation is also crucial in studying the physical, environmental and life sciences that are making real breakthroughs for people on a day-to-day basis. From the creation of new drugs and vaccines, through to the testing of revolutionary artificial organs and on to discoveries that allow diseases to be prevented, the harnessing of EM radiation on a large scale is truly expanding horizons in the scientific world.

In the UK, that revolution is happening at the Diamond Light Source national synchrotron facility in Oxfordshire. A high-tech particle accelerator that excels in generating vast quantities of EM radiation in the form of synchrotron light. We decided to take a trip to this cutting-edge science site to see what working there is like on an average day as well as what ground-breaking experiments are currently being investigated…

### Exploring the synchrotron

A good place to start would be to explain what a synchrotron actually is. Essentially it's a large, complex system of machines that generates electrons, accelerates those electrons to near light speed and then deposits them in a large storage ring. The high-energy electrons then fly around the ring circuit continuously until they are manipulated to generate very high intensity, X-ray light; we are talking about electrons with around three gigaelectronvolts (GeV), a GeV being a unit of energy equal to a billion electron volts. This is the light that scientists can utilise in their experiments.

Right now we're about to meet with Dr Guenther Rehm, head of the Diamond Synchrotron's Beamline Diagnostics Group. This is the team responsible for ensuring that when visiting scientists need X-ray light, they get it.

We step through from Rehm's office in Diamond House, a sleek, glass-walled complex in which the majority of the facility's 400 staff is based. Then once we're across the security-controlled bridge into the synchrotron facility proper, he begins to describe how the system works.

The synchrotron here consists of four main parts, the first of which is an electron gun. Sitting at the heart of the facility, this gun is responsible for generating electrons – by heating a high-voltage cathode in a vacuum – and then forcing them to bunch up together and compress into compact groups; the latter is achieved by passing the beam of electrons through a cavity where an alternating electric field is active.

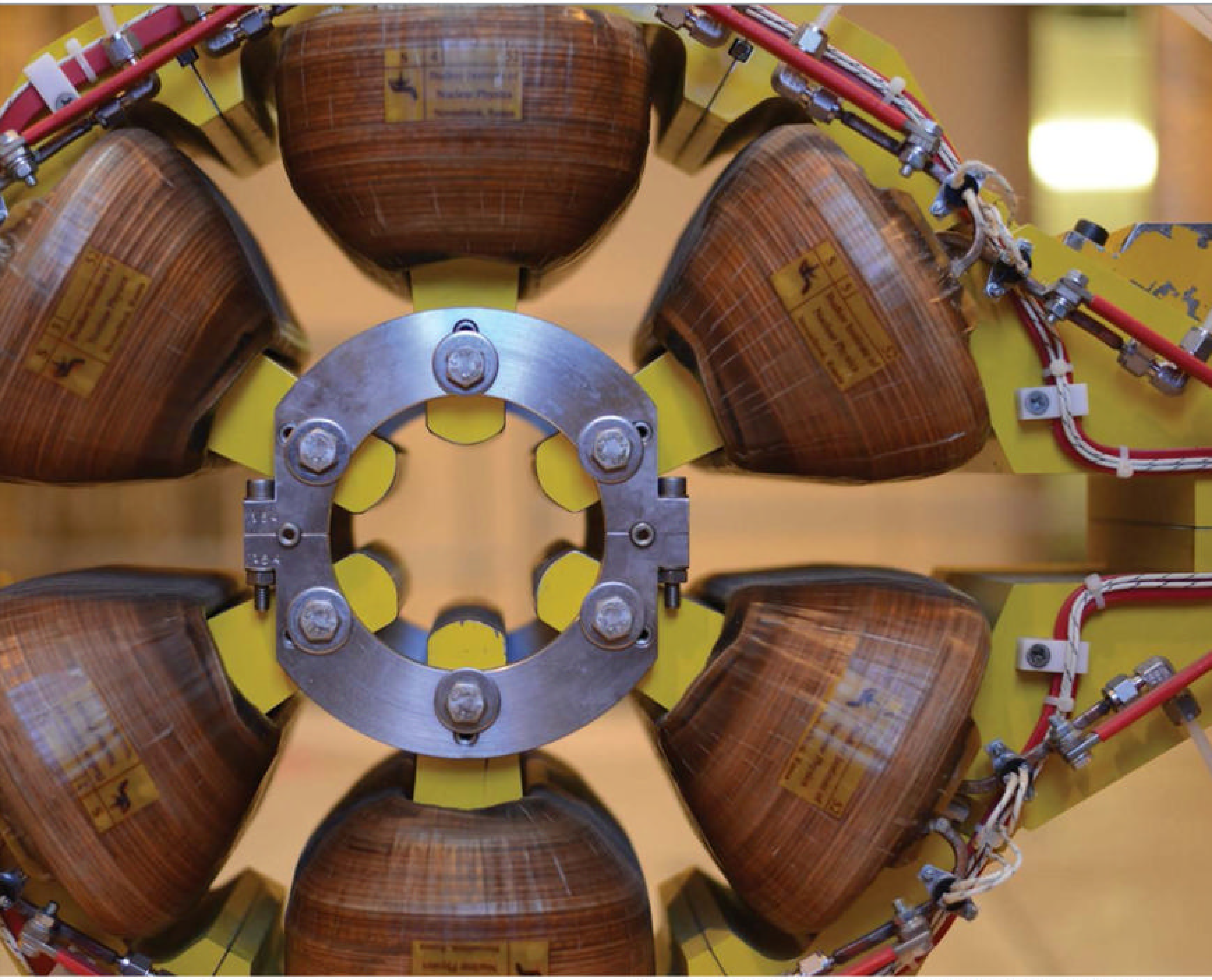
From the bunching cavity, a beam of compressed groups of electrons passes into a linear accelerator. This part of the synchrotron uses a series of electric fields to force the compressed groups of electrons in the stream to accelerate to close to the speed of light and up to a charge level of approximately 100 MeV. From here the sped-up bunches of electrons are injected into the booster synchrotron.

The booster synchrotron sits just off the linear accelerator. It is a 158m (518ft), 'O'-shaped stainless-steel tube vacuum surrounded by magnets that sits within the synchrotron's storage ring and other facilities. This smaller synchrotron receives the electrons and then, with the help of 36 dipole magnets, bends them around the vacuum circuit while they are accelerated further up to the necessary extraction energy of three GeV. Travelling at almost the speed of light and carrying an insane energy level, the electron bunches are lastly injected into the synchrotron's storage ring.

The storage ring is similar in both build and purpose to the booster ring, but on a far larger scale. The storage ring consists of a vacuum in which the charged electrons travel, a series of magnets including dipole-bending magnets to manoeuvre the beam around the circuit, quadrupole and sextupole magnets to ensure accurate beam focus

One of the synchrotron's sextupole magnets. These are responsible for achromatic correction and maintenance of a stable electron orbit within the facility's storage ring

**DID YOU KNOW?** *By 2018, the Diamond synchrotron will boast 32 beamlines*



The Diamond synchrotron is located near the city of Oxford in the UK. Its advanced technology attracts scientists from all over the world and position, as well as special magnets called insertion devices (IDs) to manipulate electrons for synchrotron light production.

The IDs are the real stars of the synchrotron, capable of forcing passing electrons to oscillate around their straight course. As a result of their resistance, super-powerful X-rays are produced. As such, prior to any beamline – offshoots from the ring where experiments take place – you'll find an ID. The electrons enter the device, oscillate, create X-rays and then, while the electrons are flung farther down the storage ring by dipole magnets, photons continue straight, down the beamline for use in experiments.

## Staying in control

Next we arrive at beamline central control. A large spacious room overlooking approximately a third of the expanding facility, the area is filled with a main bank of monitors, two members of the diagnostics team manning computer systems. Rehm explains that the day-to-day operation of the synchrotron is heavily automated, hence the minimal staffing. However, due to the incredible complexity of the systems involved in creating and maintaining high-energy electron beams, the status of the complex has to be constantly monitored. Indeed, we had expected that controlling an electron beam of such magnitude would be no easy feat.

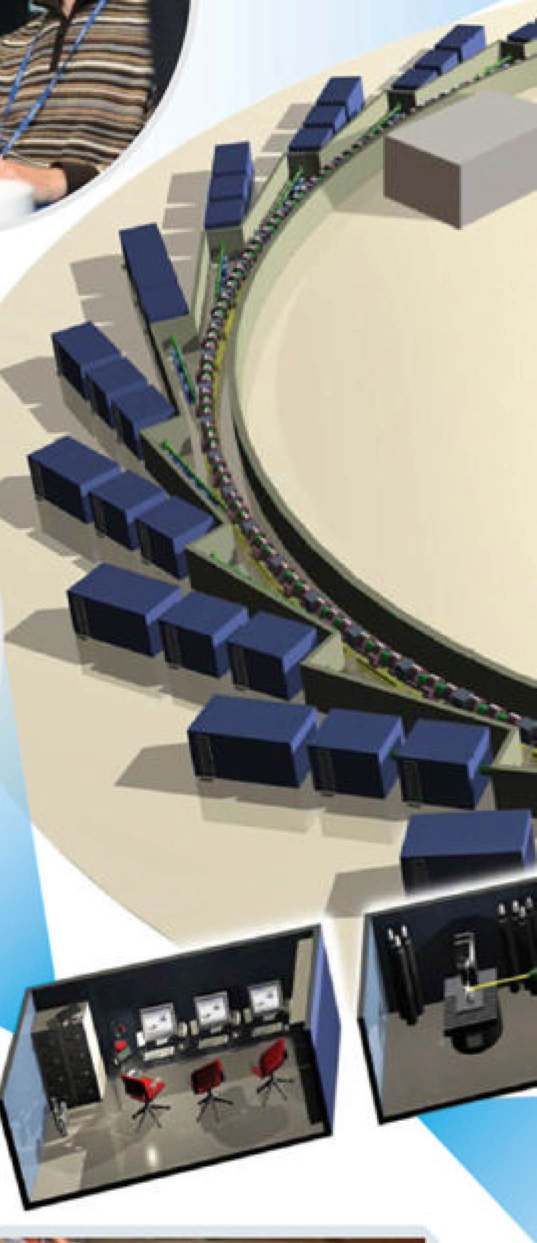
At all times the beam in the storage ring at the synchrotron is analysed within the control room for charge level, position, time structure and electron losses. This is done through a piece of software referred to as EPICS: Experimental Physics and Industrial Control System. This allows the invisible beam's properties to be visualised via a variety of sensors, monitors and cameras within the ring.

In a demonstration of how this works, Rehm shows how over a ten-minute period the bunched electrons in the storage ring suffer inevitable loss. This is due to collisions and residual gas molecules, as well as energy loss through the generation of synchrotron light by the insertion devices and bending by the dipole magnets. To maintain optimal beam stability and synchrotron light quality, it is automatically topped up periodically. Watching a live graph in EPICS, we see how the overall charge level drops within the ring and then, precisely after ten minutes, returns back to its start level.

Rehm explains that not only is this topping up automatic, but the system can actually target the parts of the beam in which the electrons have

**Diagnostics centre**
The synchrotron's operation is controlled and monitored from a central control room. Despite many systems being automated, the room is permanently staffed in case of a serious error.

**Control cabin**
This is the final hutch of each beamline and is where the scientific teams monitor and control their experiments and equipment.



## IDs up close

Insertion devices (IDs) are arrays of incredibly strong magnets lined up in two rows – top and bottom – next to each other in tight lines that have very strong magnetic fields. The magnets are arranged to generate a specific pattern of vertical alternating magnetic field that, when electrons pass through it, causes them to oscillate (vibrate back and forth). This oscillating motion generates synchrotron radiation/light in the form of photons, which can then be siphoned off for various different experiments in synchrotron facilities.

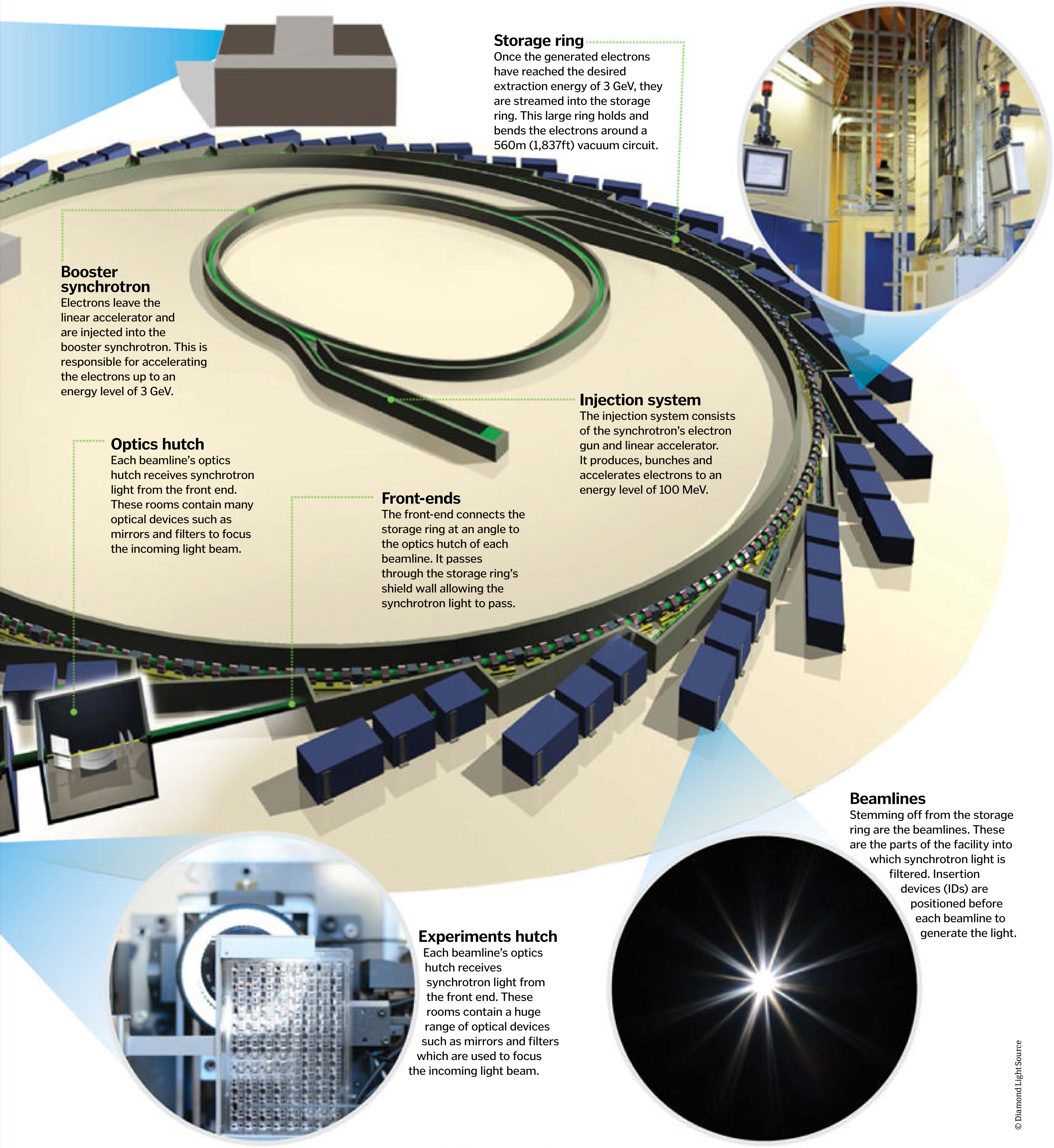
RECORD BREAKERS
ELECTRONS

## 300,556

### KILOMETRES ELECTRONS TRAVEL

Electrons in the synchrotron's storage ring complete a circuit in just 2-millionths of a second, that's the equivalent of travelling around the Earth's equator 7.5 times, a distance of 300,556km.

**DID YOU KNOW?** *The storage ring is actually not a circle, but a 24-sided polygon*



**Storage ring**
Once the generated electrons have reached the desired extraction energy of 3 GeV, they are streamed into the storage ring. This large ring holds and bends the electrons around a 560m (1,837ft) vacuum circuit.

**Booster synchrotron**
Electrons leave the linear accelerator and are injected into the booster synchrotron. This is responsible for accelerating the electrons up to an energy level of 3 GeV.

**Injection system**
The injection system consists of the synchrotron's electron gun and linear accelerator. It produces, bunches and accelerates electrons to an energy level of 100 MeV.

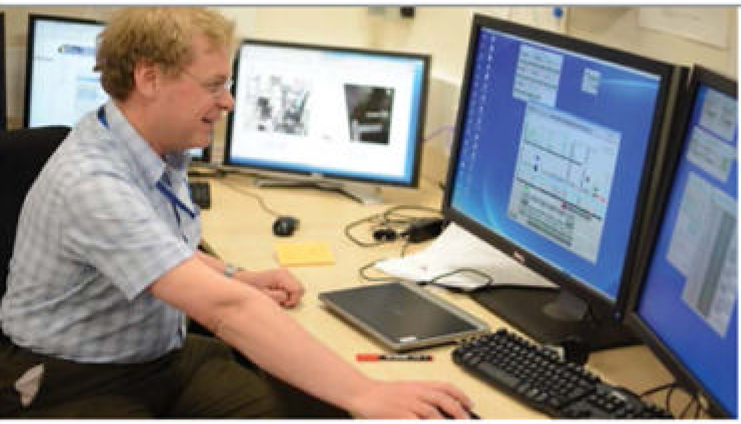
**Optics hutch**
Each beamline's optics hutch receives synchrotron light from the front end. These rooms contain many optical devices such as mirrors and filters to focus the incoming light beam.

**Front-ends**
The front-end connects the storage ring at an angle to the optics hutch of each beamline. It passes through the storage ring's shield wall allowing the synchrotron light to pass.

**Beamlines**
Stemming off from the storage ring are the beamlines. These are the parts of the facility into which synchrotron light is filtered. Insertion devices (IDs) are positioned before each beamline to generate the light.

**Experiments hutch**
Each beamline's optics hutch receives synchrotron light from the front end. These rooms contain a huge range of optical devices such as mirrors and filters which are used to focus the incoming light beam.

© Diamond Light Source



An internal view of the Diamond Light Source facility. The yellow line visible front-centre demarks the path of the electron beam within the storage ring

been lost from; this makes for an even, stable distribution of energy around the ring for light generation at all times. This system is truly amazing, capable of injecting additional electrons into the depleted electron bunches smoothly as they fly around the storage ring at almost light speed.

## Looking down the beamline

Moving to the heart of the facility, we enter the cavernous main room of the synchrotron. Standing on an elevated gantry bridge, stretching out to both sides, the curved expanses reveal many of the synchrotron's individual beamlines, branching off from a concrete ring. Rehm explains that this is the facility's storage ring, albeit encased within metre-thick, radiation-blocking concrete shielding. On top of the concrete ring is a yellow line – this identifies the actual path of the electron beam inside. According to our guide, a person could lie on top of the concrete for an entire year and only receive a radiation increase of approximately 50 per cent over that from standard background radiation. Simply put, very little radiation escapes the ring.

As we progress to get a better look at the storage ring and beamlines, Rehm begins to tell us about a major challenge of his occupation: consistency of run time.

Despite the synchrotron having a day's downtime every week for maintenance, trying to keep all the various systems and subsystems working together continuously without failure is challenging. Scientists are visiting the facility 24/7 and spend months applying and waiting for their chance to use a beamline, so any unscheduled downtime is keenly felt.

It is some of those scientists that How It Works is about to meet, but first Rehm has one more stop. Sandwiched between two beamlines is a small, black room. On entering, we find a large table stuffed with machines, pipes, optics and cabling. Behind this, a small hole is cut in the wall. This is the Optics Diagnostics Cabin and it allows the support scientists to explore the temporal structure of the stored electron beam, revealing its fill pattern (how much charge is in each of the electron bunches). Rehm holds his hand in front on the incoming beam of light to reveal its apparent weakness, like a faint splodge. We then look down the incoming beam and are immediately dazzled by a piercing bright light. This is but a minuscule replica of the high-energy synchrotron light in the beamlines.

## Handling the light

Knowing how the synchrotron works is one thing, but what does it actually mean for the world at large? Enter Professor Nick Terrill, the principal beamline scientist for the small angle scattering and diffraction beamline (I22). Among many other examples, Terrill described how a team recently had used I22 to test new polymer-material artificial heart valves. The team built a tiny device to stretch the valve to reproduce the effects of a heart beat and then used the synchrotron's high-energy X-ray light source to image the internal structure of the polymer valve in continuous resolution over a long period. It is hoped these sort of polymer valves could soon replace the problematic mechanical and animal implant valves currently used.

After a short walk around the synchrotron's outer walkway to beamline I24, we come across the microfocus macromolecular crystallography station. I24 is staffed by Diamond's senior support scientist, Dr Danny Axford, who explains how the team is working on membrane proteins, exploring their structures –something of vital importance in the creation of new drugs among other applications. This project is a collaboration between Imperial College London and Diamond itself. It is making use of both the on-site Membrane Protein Lab, which negates the need to transport samples and potentially damage them, as well as a new technique in

**THE STATS**
**SYNCHROTRON**

| | | | | | |
|---|---|---|---|---|---|
| AREA OF FACILITY | 43,300m$^2$ | STORAGE RING SIZE | 562m | COST TO BUILD | £260mn |
| STORAGE RING BENDING MAGNETS | 48 | CURRENT NUMBER OF BEAMLINES | 22 | ELECTRON BEAM CHARGE | 3 GeV |

**DID YOU KNOW?** *Over 400 people work at the Diamond synchrotron facility*

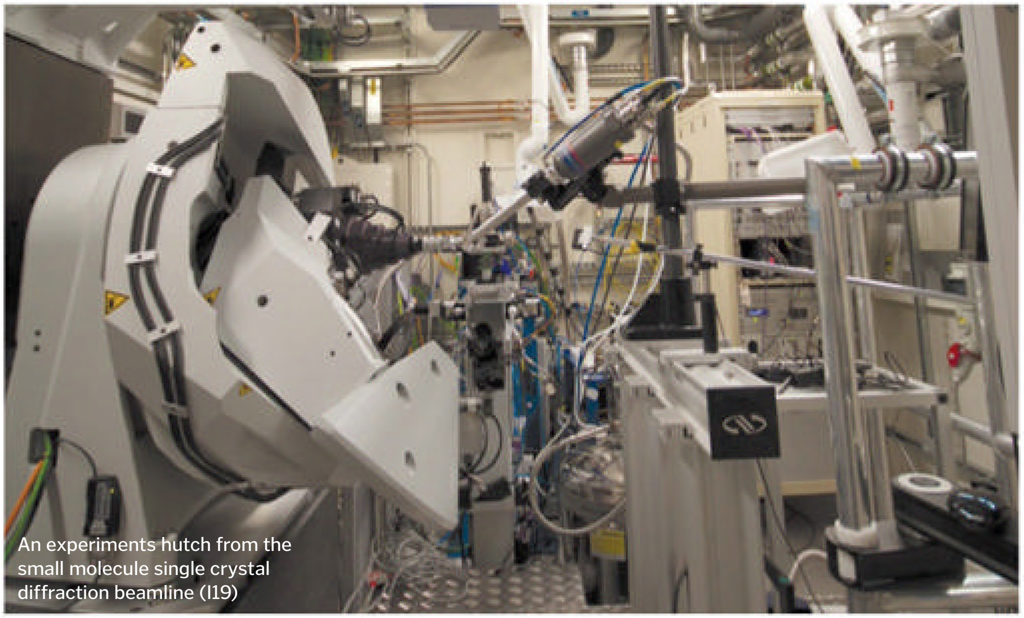
05
05
06
BEAMLINE
I05

which a wide variety of crystal samples can be imaged in a short space of time.

After allowing the visiting scientists to finish analysing their current batch of samples, Axford opens up I24's experiment's hutch – the room containing the liquid-nitrogen storage tanks, imaging sensor, robotic arm, synchrotron light-focus optic and sample array all needed to perform experiments. The sensor in this room is state of the art and, alongside the sample-holding array, allows rows of crystals to be imaged at room temperature. This is incredibly useful as heat from the imaging process damages crystals, so capturing their structure quickly is crucial – hence why many samples are cryogenically cooled.

Our next port of call is the small molecule single crystal diffraction beamline (I19), where we see how a variety of crystallised samples are being analysed through diffraction techniques with samples ranging in areas from cancer to hydrogen storage. Next door, in I20, we get a detailed tour of the impressive versatile X-ray absorption spectroscopy beamline by principal beamline scientist Dr Sofia Diaz-Moreno.

This beamline, which is much larger than any of the others, has two experiment hutches that share the line to enable different types of spectroscopy analysis. What really excites us is hearing about how important chemical components in catalysts – even in very low concentrations – can have their structure illuminated and imaged continuously. This ability to image reaction processes at an atomic level and at microsecond time scales is truly mind-blowing, and is allowing scientists to understand things like catalysts, metalloproteins (metal ion-containing proteins) and toxic materials like never before.


An experiments hutch from the small molecule single crystal diffraction beamline (I19)

## Racing the electron beam

After witnessing first hand just how this impressive facility is enabling scientists to make radical breakthroughs in many fields of science, we have time for one final stop: a stroll on the roof of the storage ring. Ascending back up to the first floor from beamline level and crossing the metal gantry towards the centre of the facility, we break off and step directly on top of the concrete roof of the storage ring, before following the yellow beamline marker around the facility. It takes us close to ten minutes to make a full circuit around the ring; by way of comparison it takes the hyper-charged electrons beneath our feet just 2-millionths of a second.

# BIOTECH

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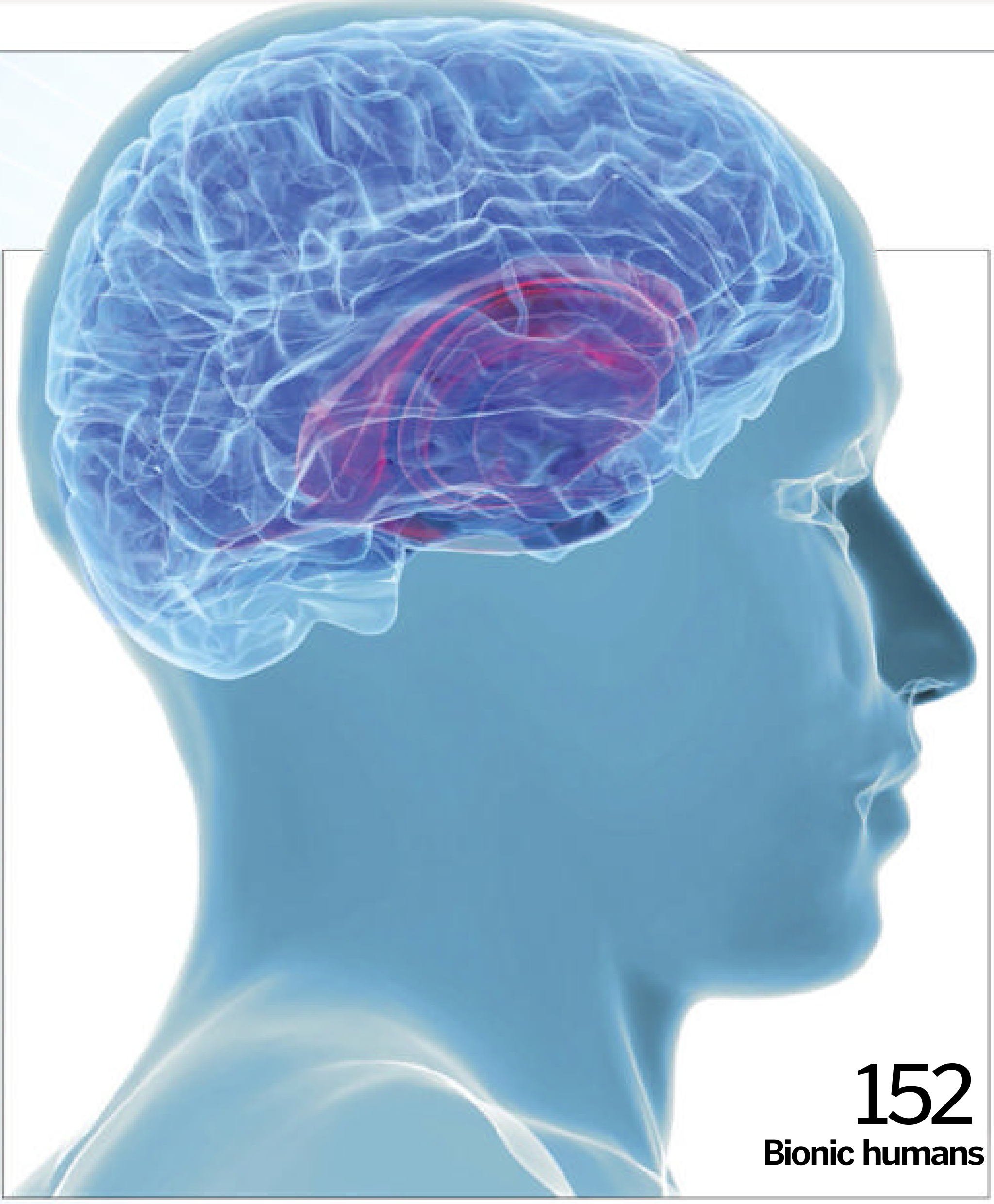

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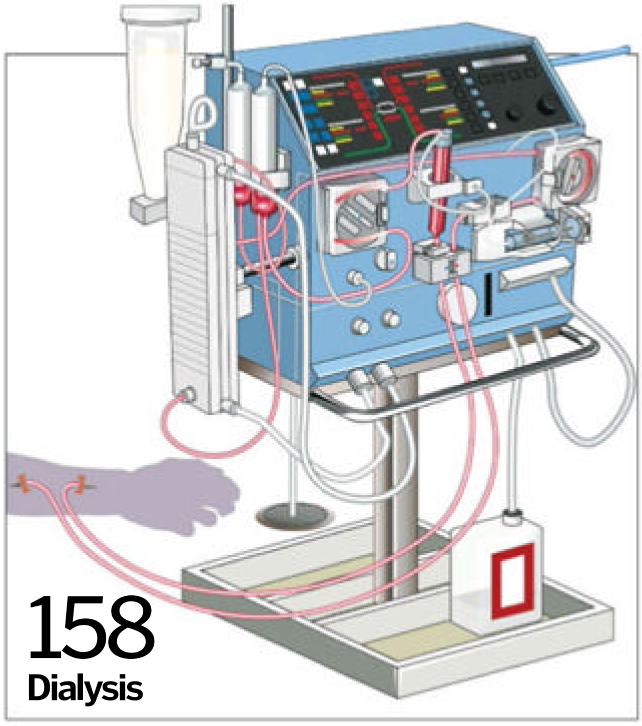

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# BIONIC HUMANS

Discover the medical technology that really could make us better, faster, stronger…

Bionics experts attempt to build mechanical and electronic devices to mimic biological functions. With the exception of the brain, the human body can essentially be broken down and rebuilt using a combination of mechanical, electronic and biological technologies.

A bionic limb strips human biology back to its constituent parts. Tough materials like aluminium and carbon fibre replace the skeleton, motors and hydraulics move the limb, while springs replace the tendons that store and release elastic energy. A computer controls motion and wires relay electrical signals, as nerves would have done in a real limb. Users are now even able to control these limbs with their minds (see 'The power of thought').

Technology is also in development to replace individual muscles and tendons following injury. The synthetic muscles are made from a polymer gel, which expands and contracts in response to electrical currents, much like human muscle. The tendons are made from fine synthetic fibres designed to imitate the behaviour of connective tissue.

The mechanical nature of limbs makes them excellent candidates for building robotic counterparts, and the same applies to the human heart. The two ventricles, which supply blood to the body and lungs, are replaced with hydraulically powered chambers. However, it's not just the mechanical components of the human body that can be replaced; as time goes on, even parts of the complex sensory system can be re-created with technology.

Cochlear implants, for example, use a microphone to replace the ear, while retinal implants use a video camera to stand in for the human eye. The data that they capture is then processed and transformed into electrical impulses, which are delivered to the auditory or optic nerve, respectively, and then on to the brain. Bionic touch sensors are also in development. For example, the University of California, Berkeley, is developing 'eSkin' – a network of pressure sensors in a plastic web. This could even allow people to sense touch through their bionic limbs.

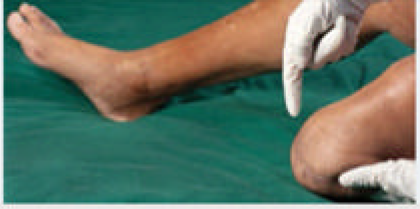
Replacing entire organs is one of the ongoing goals of bionic research. However, breaking each organ down and re-creating all of its specialised biological functions is challenging.

If only part of an organ is damaged, it's simpler to replace the loss of function using bionics. In type 1 diabetes, the insulin-producing beta cells of the pancreas are destroyed by the immune system. Some

**STRANGE BUT TRUE**
**LIMB LOSS CULPRIT**

## What is the number one cause of limb amputation?

**A Car accident B Diabetes C Lightning**



**Answer:**
Diabetes is the leading cause of lower limb amputation. High blood sugar damages the nerves and blood vessels in the feet, which can lead to ulcers and eventually gangrene.

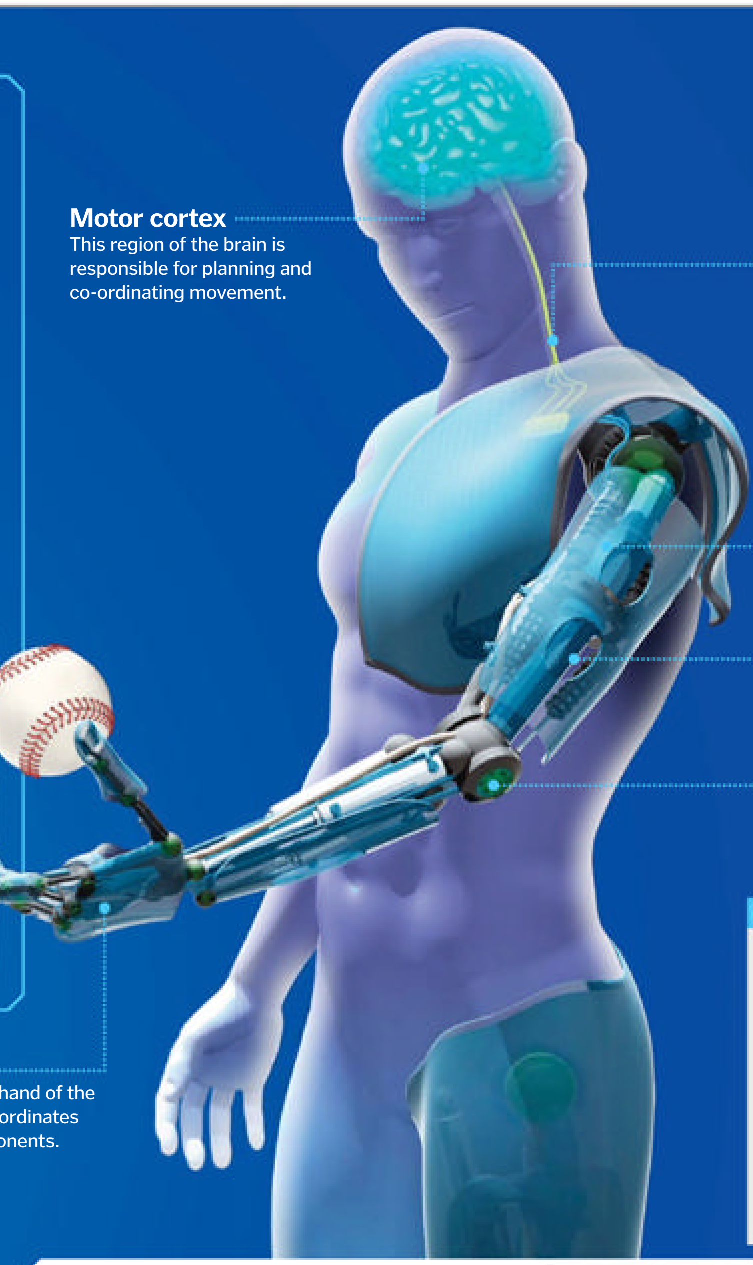
**DID YOU KNOW?** An artificial heart implant operation costs about £80,000 ($125,000) and £11,500 ($18,000) a year to maintain

## The power of thought explained

Cutting-edge bionic limbs currently in development allow the user to control movements with their own thoughts. Technically called 'targeted muscle reinnervation' it's a groundbreaking surgical technique that rewires the nerves in an amputated limb. The remaining nerves that would have fed the missing arm and hand are rerouted into existing muscles. When the user thinks about moving their fingers, the muscles contract, and these contractions generate tiny electrical signals that can be picked up by the prosthetic.

The prosthetic is then programmed to respond to these muscle movements, taking each combination of signals and translating it into mechanical movement of the arm. Some of the most sophisticated have 100 sensors, 26 movable joints and 17 motors, all co-ordinated by a computer built into the prosthetic hand.

A scientist controls a wheelchair using a brain-machine interface



**Motor cortex**
This region of the brain is responsible for planning and co-ordinating movement.

**Rerouted nerves**
The nerves that used to feed the missing limb are rewired into existing muscles.

**Sensors**
Sensors pick up tiny electrical signals when the user thinks about moving.

**Motors**
A series of motors replace the biological function of muscles.

**Joints**
Joints are designed to match the natural range of human motion.

**Computer**
A computer in the hand of the prosthetic arm co-ordinates all the other components.

**Learn more**

If this bionics feature piques your interest, why not visit London's FutureFest (14-15 March 2015) where you can witness compelling talks, cutting-edge shows, technology displays and interactive performances, hearing from such speakers as the controversial Edward Snowden. For more info visit: **futurefest.org**.

patients are now fitted with an artificial pancreas: a computer worn externally, which monitors blood sugar and administers the correct dose of insulin as required.

Entire organ replacements are much more complicated, and scientists are turning back to biology to manufacture artificial organs. By combining 3D printing with stem cell research, we are now able to print cells layer by layer and build up tissues. In the future, this could lead to customised organ transplants made from the recipient's very own cells.

Advances in bionics mean that already limbs are emerging that exceed human capabilities for weight bearing and speed. That said, the sheer complexity of our internal organs and how they interact means that it is not yet possible to fully replace man with machine. But maybe it's just a matter of time... ✪

## The right materials

One of the most important factors in biomedical engineering is biocompatibility – the interaction of different materials with biological tissues.

Implanted materials are often chosen because they are 'biologically inert' and as a result they don't provoke an immune response. These can include titanium, silicone and plastics like PTFE. Artificial heart valves are often coated in a layer of mesh-like fabric made from the same plastic used for soft drink bottles – Dacron. In a biological context, the plastic mesh serves as an inert scaffold, allowing the tissue to grow over the valve, securing it in place. Some scaffolds used in implants are even biodegradable, providing temporary support to the growing tissue, before harmlessly dissolving into the body.

Bionic limbs are worn externally, so their materials are chosen for strength and flexibility as opposed to biocompatibility. Aluminium, carbon fibre and titanium are all used as structural components, providing huge mechanical strength.

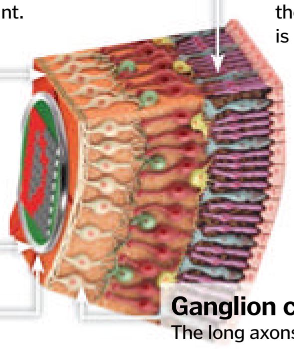
Artificial heart valves are often made from metal, such as titanium or stainless steel

# Building a bionic human

Advances in technology make it possible to build limbs with components that mimic the function of the skeleton, musculature, tendons and nerves of the human body. Meanwhile, the sensory system can be replicated with microphones, cameras, pressure sensors and electrodes. Even that most vital organ, the heart, can be replaced with a hydraulic pump. Some of the newest technologies are so advanced that the components actually outperform their biological counterparts.

## Retinal implant

**Argus II, Second Sight**
A camera mounted on a pair of glasses captures real-time images and transmits them wirelessly to an implant on the retina. The implant contains 60 electrodes and, depending on the image, will generate different patterns of electrical signals, which are then sent to the remaining healthy retinal cells. These cells are activated by the signals, and carry the visual information to the brain for processing.



**Interface**
Nerve cells respond to electrical signals made by the implant.

**Rods and cones**
Light detection by the eye's own cells is not necessary.

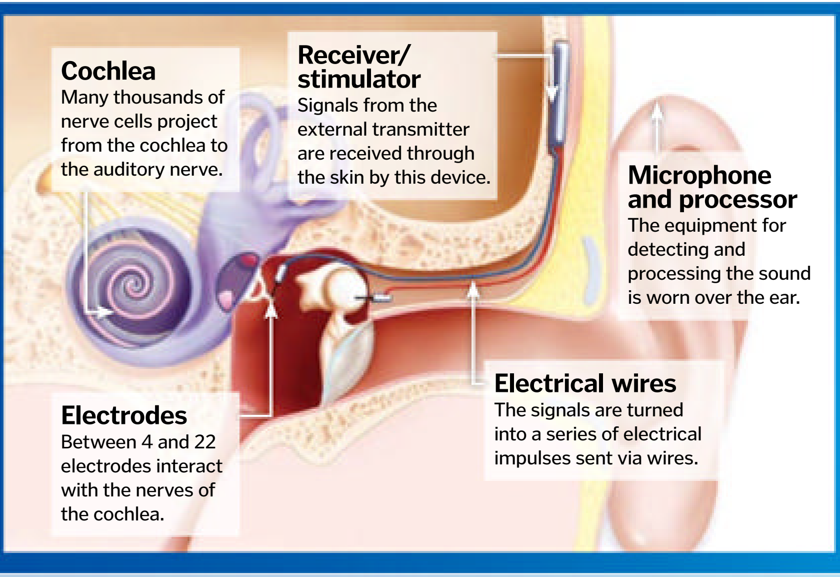
**Wireless technology**
Video signals are sent wirelessly to the implant.

**Implant**
The implant transmits signals via 60 electrodes.

**Ganglion cells**
The long axons of these cells make up the optic nerve.

## Cochlear implant

**Nucleus 6, Cochlear**
A cochlear implant has four main components. A microphone, worn near the ear, detects audio and transmits a signal to a sound processor. The processor then arranges the signal and sends it to a built-in transmitter. The transmitter passes the signal to an implanted receiver/stimulator, which transforms it into electrical stimuli for the electrodes. Finally these signals are relayed to the auditory nerve.



**Cochlea**
Many thousands of nerve cells project from the cochlea to the auditory nerve.

**Receiver/stimulator**
Signals from the external transmitter are received through the skin by this device.

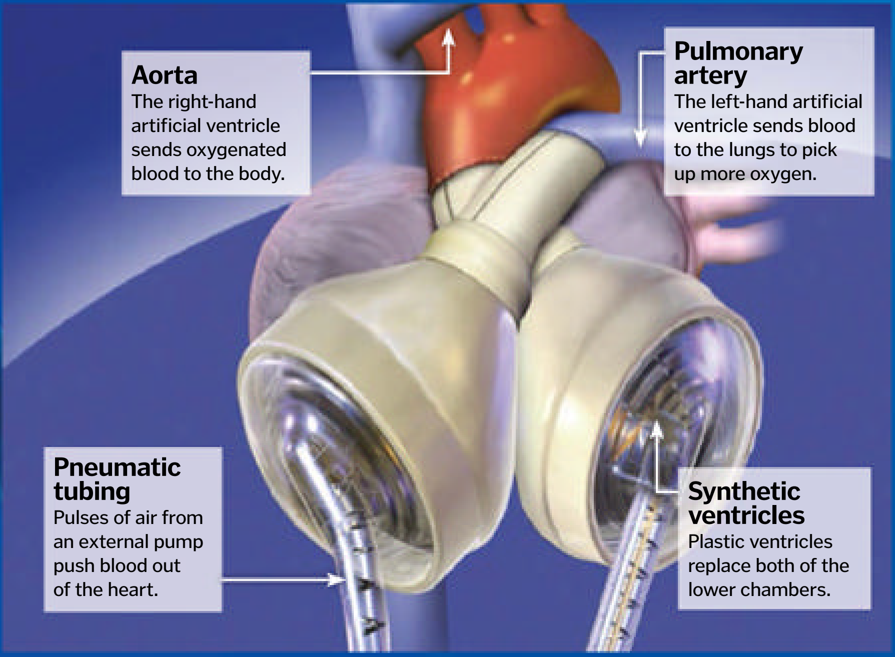
**Microphone and processor**
The equipment for detecting and processing the sound is worn over the ear.

**Electrodes**
Between 4 and 22 electrodes interact with the nerves of the cochlea.

**Electrical wires**
The signals are turned into a series of electrical impulses sent via wires.

## Artificial heart

**Total Artificial Heart, SynCardia Systems**
Plastic hearts can be implanted to replace the two ventricles of the heart. Plastic tubing is inserted to replace the valves, and two artificial chambers are also attached. The heart is then connected to a pneumatic pump worn in a backpack, which sends bursts of air to the chambers, generating the pressure that's required to pump blood around the body.



**Aorta**
The right-hand artificial ventricle sends oxygenated blood to the body.

**Pulmonary artery**
The left-hand artificial ventricle sends blood to the lungs to pick up more oxygen.

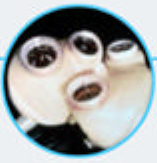
**Pneumatic tubing**
Pulses of air from an external pump push blood out of the heart.

**Synthetic ventricles**
Plastic ventricles replace both of the lower chambers.

## KEY DATES
BIONICS FIRSTS

**500 BCE**
The first known mention of a wooden prosthetic limb, worn by a prisoner after his foot was amputated.

**1957**
The first cochlear implant is created. Sounds are unprocessed, but it does help with lip reading.



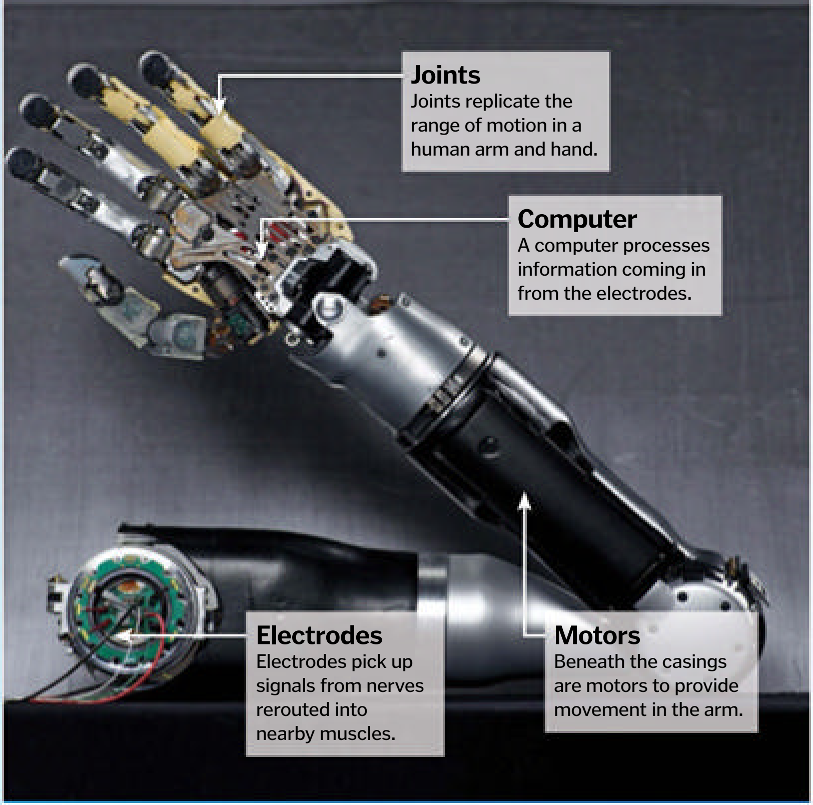
**1982**
The first successful artificial heart implant operation is performed at the University of Utah.

**2011**
The first artificial trachea transplant takes place in Sweden, using a synthetic scaffold coated in stem cells.

**2013**
The Argus II retinal implant is licensed, enabling patients with retinitis pigmentosa to see again.

**DID YOU KNOW?** *In 1812 a prosthetic arm was invented that could be moved using cables attached to the opposite shoulder*

## Bionic arm



**Joints**
Joints replicate the range of motion in a human arm and hand.

**Computer**
A computer processes information coming in from the electrodes.

**Electrodes**
Electrodes pick up signals from nerves rerouted into nearby muscles.

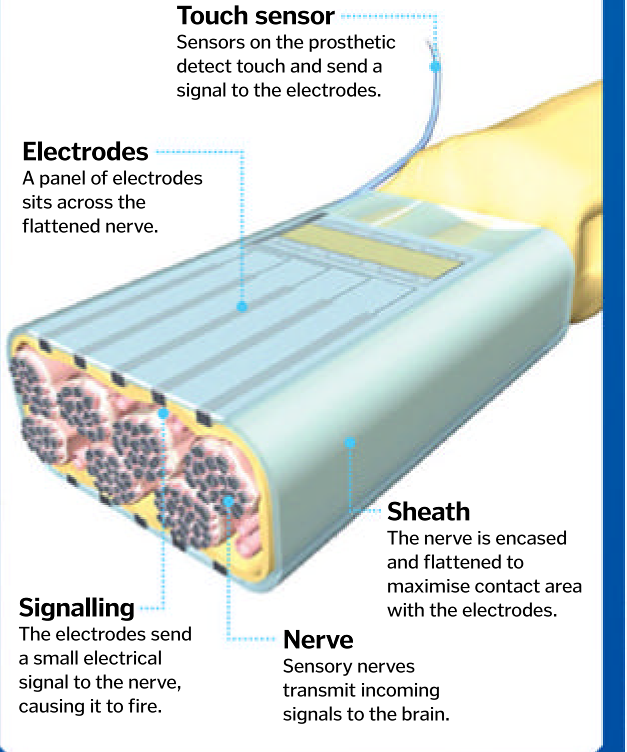
**Motors**
Beneath the casings are motors to provide movement in the arm.

## Bionic limbs

Prosthetic limbs have come on leaps and bounds in the past couple of decades. They still retain characteristic features, such as an internal skeleton for structural support and a socket to attach to the amputation site, however the most innovative models are now able to reproduce, or even exceed, biological movements. Motors are used in place of muscles, springs instead of tendons and wires instead of nerves.

The movement of many prosthetics is controlled externally, using cables attached to other parts of the body, or using a series of buttons and switches. New technology is emerging to allow the user to move the limb using their mind (see 'The power of thought'). The next logical step in this process is developing technology that enables the prosthetic limb to sense touch, and relay the information back to the user. DARPA-funded researchers have developed FINE, a flat interface nerve electrode (see below left) which brings nerves into close contact with electrodes, allowing sensory data to pass to the brain.

## Touch-sensitive prosthetics



**Touch sensor**
Sensors on the prosthetic detect touch and send a signal to the electrodes.

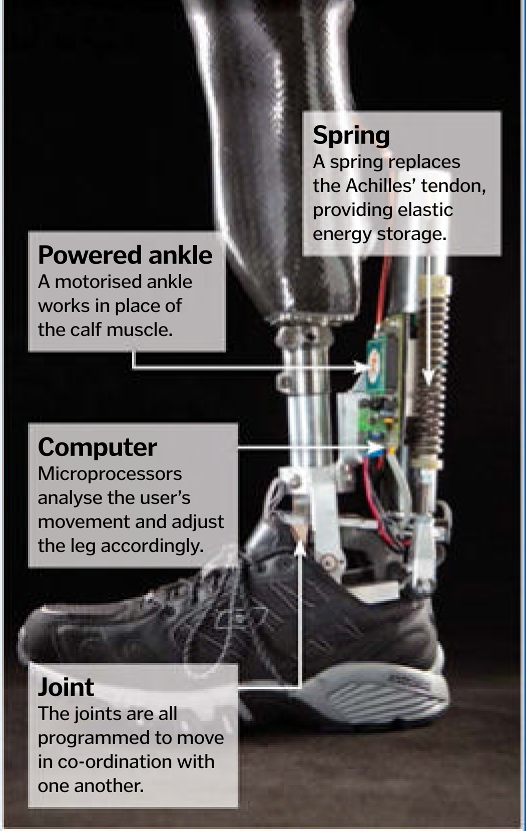
**Electrodes**
A panel of electrodes sits across the flattened nerve.

**Sheath**
The nerve is encased and flattened to maximise contact area with the electrodes.

**Signalling**
The electrodes send a small electrical signal to the nerve, causing it to fire.

**Nerve**
Sensory nerves transmit incoming signals to the brain.

## Bionic leg



**Spring**
A spring replaces the Achilles' tendon, providing elastic energy storage.

**Powered ankle**
A motorised ankle works in place of the calf muscle.

**Computer**
Microprocessors analyse the user's movement and adjust the leg accordingly.

**Joint**
The joints are all programmed to move in co-ordination with one another.

## The future of bionics

### 1 3D-printed organs
Biologists are adapting the technology in order to print using living human cells. The cells are laid down in alternating layers alongside a transparent gel-like scaffold material. As the cells fuse, the scaffold disappears. For more info, go to page 168.

### 2 Ekso skeleton
Ekso Bionics has made bionic exoskeletons to allow people with lower limb paralysis to walk. Ekso supports their body and uses motion sensors to monitor gestures and then translate them into movement. Read more on page 170.

### 3 Artificial kidney
The University of California, San Francisco, is developing a bionic kidney. At about the size of a baseball, it contains silicone screens with nano-drilled holes to filter blood as it passes. It will also contain a population of engineered kidney cells.

### 4 Man-made immunity
Leuko-polymersomes are plastic 'smart particles' that mimic cells of the immune system. They are being designed to stick to inflammatory markers in the body and could be used to target drug delivery to infections and cancer.

### 5 Robotic blood cells
The Institute for Molecular Manufacturing is developing nanotechnology that could increase the oxygen-carrying capacity of blood. Known as respirocytes, the cells are made atom by atom – mostly from carbon.

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# Medical ventilators

## How these breathing machines perform their life-saving task

Breathing is one of the most natural things in the world. It's the first thing we do when we're born and we go on doing that automatically for the rest of our lives. But sometimes people need assistance with their breathing if they have respiratory issues or are under anaesthetic during an operation.

This is where the ventilator comes in. It is a machine that contains oxygen and air, which is pumped through a tube, either into your mouth or into a surgical hole in your neck, by increasing pressure in the machine, pushing the air into the lower pressure area of your lungs.

The second option is used for people who will need to be on the ventilator for longer as it is more comfortable and may allow the user to talk. The breathing tube will push air into your lungs, where it can be circulated around the body, and will also take the leftover carbon dioxide out of your body. This is called the endotracheal tube as it goes into the trachea or windpipe. It stays on your face by a strap that goes around your head. Settings on the ventilator regulate how often air is pumped into the lungs every minute, although the user can increase this if they are feeling short of breath.

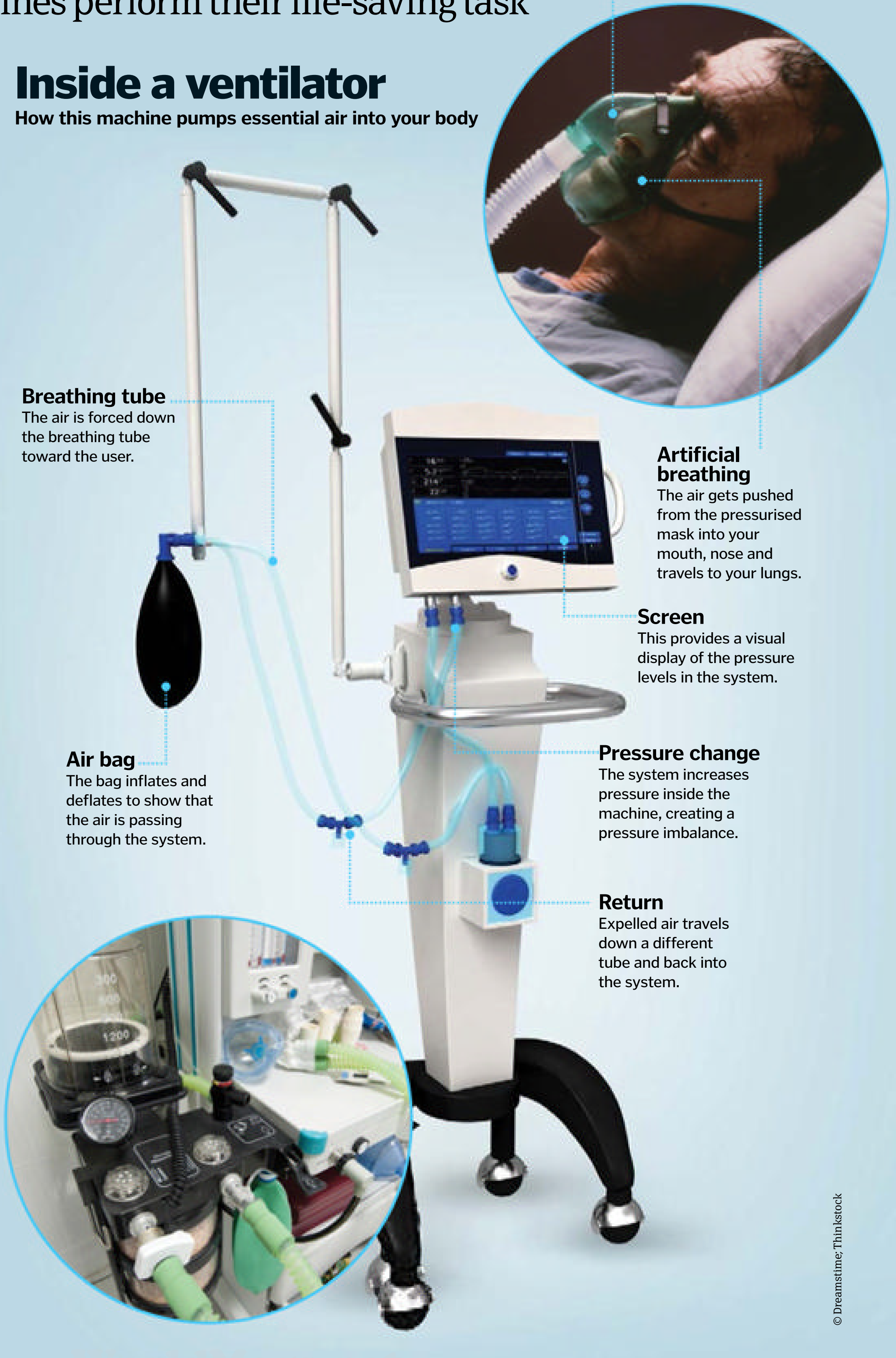
### The original respirator

Respirators have been around since the late 1920s when Philip Drinker and Louis Agassiz Shaw created the first widely-used negative pressure ventilator, which was more commonly known as the iron lung. It was a heavy machine, powered by vacuum cleaners and run using an electric motor. It used a pump to force air into the lungs and then draw it out again by decreasing pressure.

John Haven Emerson added a sliding tray so the user could be pushed in and out of the machine more easily, as well as windows along the side so attendants could reach in and adjust the patient. This design halved the cost of the original machine, which had been the same as a house.

## Inside a ventilator

How this machine pumps essential air into your body



**Breathing mask**
A mask is fitted over the mouth and nose so the air cannot escape.

**Breathing tube**
The air is forced down the breathing tube toward the user.

**Artificial breathing**
The air gets pushed from the pressurised mask into your mouth, nose and travels to your lungs.

**Screen**
This provides a visual display of the pressure levels in the system.

**Air bag**
The bag inflates and deflates to show that the air is passing through the system.

**Pressure change**
The system increases pressure inside the machine, creating a pressure imbalance.

**Return**
Expelled air travels down a different tube and back into the system.

© Dreamstime; Thinkstock

# The lifesaving water filter

How can a simple straw make even the dirtiest water safe to drink?

Dirty water is one of the biggest killers. However, there is now a cheap and efficient way to stop dangerous, waterborne bugs in their tracks: the LifeStraw.

The device decontaminates dirty water, making it safe for human consumption. It achieves this by using a 0.2-micrometre tube with a hollow fibre membrane that allows water through, but not dirt and virtually no pathogens like parasites and bacteria, of which over 99.9 per cent are blocked.

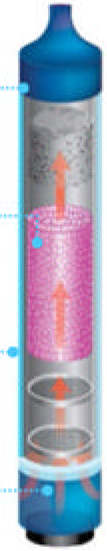
As the latest iteration of the LifeStraw doesn't use electricity or chemicals, it's ideal for remote, impoverished areas experiencing drought or an unreliable water supply. It can process up to 1,000 litres (264 gallons).

It's already helped during the aftermath of natural disasters and mainly targets diarrhoea and Guinea worm disease: leading causes of death in developing countries.

The LifeStraw aims to reduce the spread of disease by providing clean water to all

## LifeStraw up close

**See what's happening inside these pocket-sized water filters**



**Mouthpiece**
Safe water is now ready to drink. You just blow air through to clean the straw out and it's ready to use again.

**Filtration**
Hollow fibres in the tube trap 99.9999 per cent of bacteria and 99.9 per cent of parasites and filter out any soil particles.

**Plastic casing**
Weighing in at just 56g (2oz), the straw is very practical for distribution and compact enough to carry with you 24/7.

**Dirty water**
The potentially contaminated water is sucked up at the bottom of the device.

# Intelligent fingerprinting

The tech that enables illegal substances to be detected with just a fingerprint

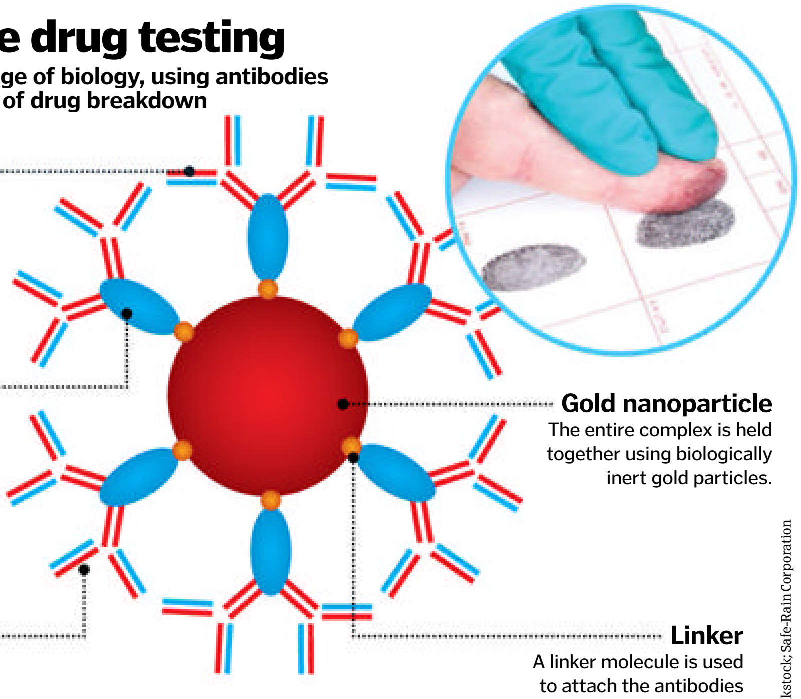
The University of East Anglia in the UK has developed a handheld device that detects the breakdown products of commonly abused drugs in sweat released from pores in the fingertips.

An image of the fingerprint is taken to create a reference point and treated with a solution containing gold nanoparticles, which stick to the breakdown products of illicit substances. The particles are stained with a fluorescent dye and a second image of the print is taken.

This test is far quicker than alternative methods and it also provides proof that a positive result belongs to the owner of the fingerprint and is not down to sample contamination. Sweat is released from pores in the fingertips and finally tracks along the fingerprint ridges, carrying with it traces of drug metabolites that gradually decrease in concentration. If the staining of the print is greatest at the pores, it provides solid evidence that the metabolites are being released from the sweat glands of the person being tested.

## Nanoparticle drug testing

**The test takes advantage of biology, using antibodies to detect the products of drug breakdown**



**Antibody**
Antibodies are generated by the immune system and can be manufactured in the laboratory to stick to almost any target.

**Protein**
In combination with the linker molecule, proteins are used to bind the antibodies to the gold nanoparticle.

**Detection**
Antibodies stick specifically to the metabolites of commonly abused substances.

**Gold nanoparticle**
The entire complex is held together using biologically inert gold particles.

**Linker**
A linker molecule is used to attach the antibodies to the gold nanoparticle.

© Thinkstock; Safe-Rain Corporation

# How dialysis cleans blood

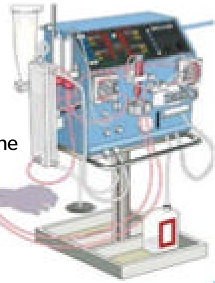
Discover how the amazing dialysis process rids your body of harmful waste

When kidneys fail to filter your blood of waste and unwanted water, we rely on dialysis. An artificial process, it takes the basic scientific principles of concentration gradients and diffusion to filter out harmful substances from the bloodstream, such as extra salt and excess fluids. A dialysis machine can control which substances are removed and at what concentration, allowing fine control of waste product removal and electrolyte balance, like sodium and potassium. Dialysis is needed when the kidneys' natural function is lost. Since you can live with one kidney, both need to be affected before dialysis is required. Common reasons for dialysis are severe diabetes and long-standing high blood pressure, while rare causes include genetic diseases.

Dialysis machines date back to the Second World War. The technology developed rapidly as it was proven to save lives and today there are two main types: haemodialysis, which filters the blood, and peritoneal dialysis, which filters fluid within the abdomen. While life-saving, dialysis needs to be performed up to four times a week and is not without complications. A kidney transplant offers the best chance of long-term cure, but the number of patients on transplant waiting lists far exceeds the number of donated kidneys, so dialysis remains a key part of keeping people alive around the world. ❂

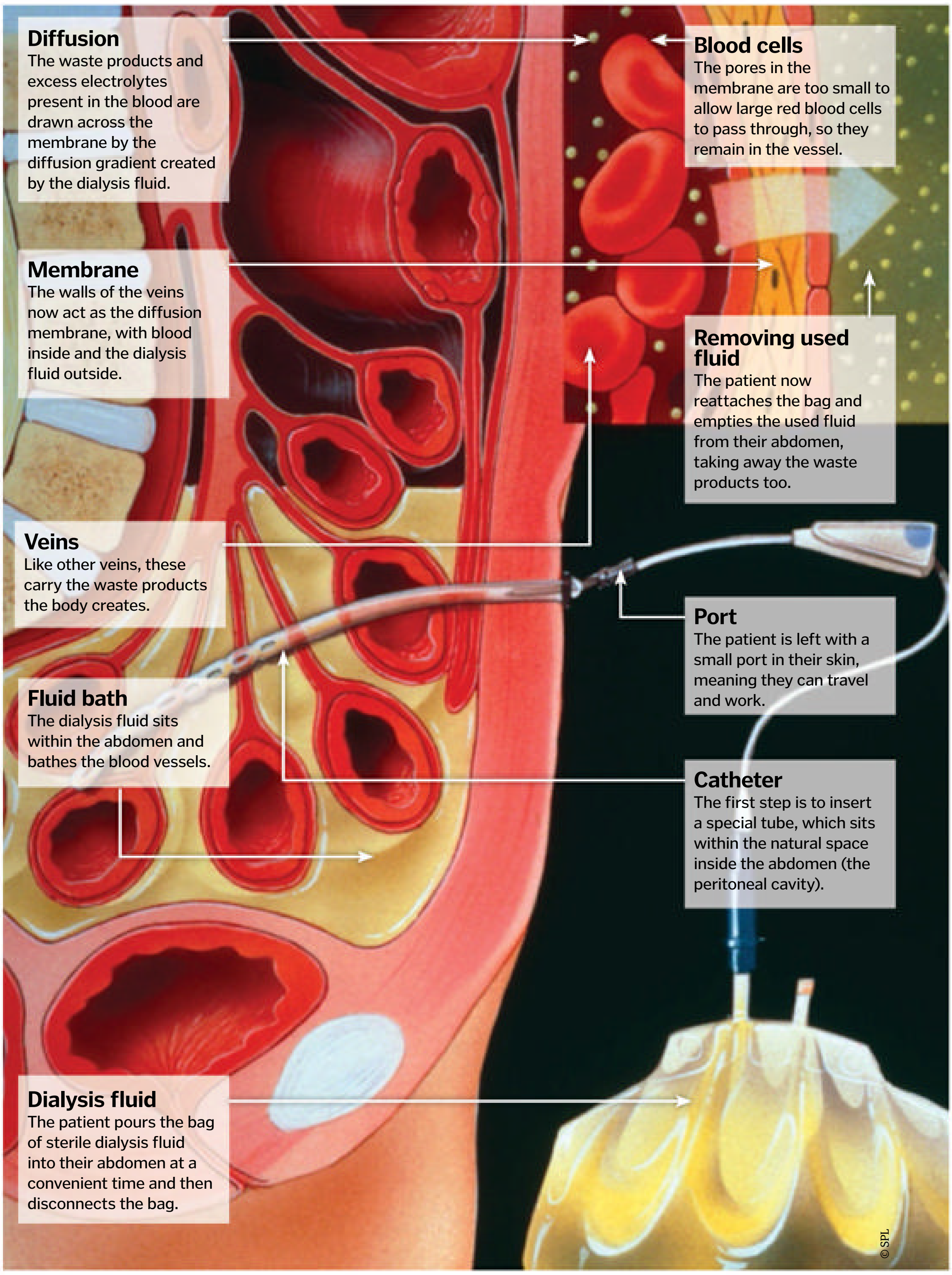
## How a dialysis machine works

Sterile tubing is attached to a vein (to take blood away from the body) and an artery (to return cleaned blood) in the patient's arm. The process relies on a semi-permeable membrane, a thin sheet with tiny holes that only allows molecules under a certain size to pass through. On one side of the membrane is the blood, carrying nutrients and waste products. On the other side is the kidney, containing early components of urine. The pores prevent large particles like red blood cells from escaping the bloodstream. This process is replicated exactly in the machine. On one side is the removed blood and on the other is a solution that draws out the waste products from the blood.



## How peritoneal dialysis works

Learn how a different type of dialysis can fit into your working life



**Diffusion**
The waste products and excess electrolytes present in the blood are drawn across the membrane by the diffusion gradient created by the dialysis fluid.

**Membrane**
The walls of the veins now act as the diffusion membrane, with blood inside and the dialysis fluid outside.

**Veins**
Like other veins, these carry the waste products the body creates.

**Fluid bath**
The dialysis fluid sits within the abdomen and bathes the blood vessels.

**Dialysis fluid**
The patient pours the bag of sterile dialysis fluid into their abdomen at a convenient time and then disconnects the bag.

**Blood cells**
The pores in the membrane are too small to allow large red blood cells to pass through, so they remain in the vessel.

**Removing used fluid**
The patient now reattaches the bag and empties the used fluid from their abdomen, taking away the waste products too.

**Port**
The patient is left with a small port in their skin, meaning they can travel and work.

**Catheter**
The first step is to insert a special tube, which sits within the natural space inside the abdomen (the peritoneal cavity).

© SPL

**DID YOU KNOW?** *Human patient simulators can be programmed to mimic just about any patient; old or young, male or female*

# Human patient simulators

## Using a combination of electronics, hydraulics and mathematical models, see how these mannequins can help us train for a real-life medical emergency

The simulation is managed by a sophisticated computer program, which integrates the incoming information from the sensors in the mannequin. Using complex mathematical models of real human physiology, the software alters the patient's condition in real-time as the medics attempt to treat the patient.

Blood vessels that are found in the arms, neck and groin pulse in time with the heart rate, which can also be monitored via electrical signals through the chest using an ECG machine. In the arm, a vein at the elbow allows a cannula to be inserted, and on-board fluids enable blood samples to be taken.

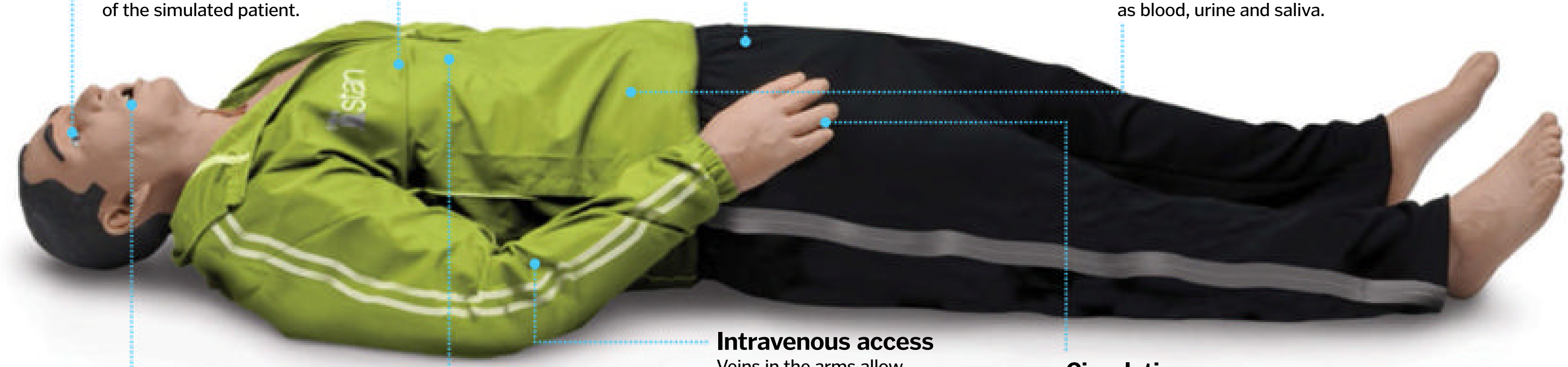
Pumps, hydraulics and motors, meanwhile, are used to control the patient's movements, by opening and closing the eyes, making the chest rise and fall, and even allowing for simulated convulsions.

The mannequin is packed with sensors in order to detect treatments as and when they are administered. If the procedure happens to be performed incorrectly, the simulation will react just as an actual patient would.

The most sophisticated simulators also allow drugs to be administered and are even able to respond based on the type and dosage, using a barcode system in order to alert the computer to the incoming medication.

## Inside a patient simulator

**These advanced medical training aids are packed with technology that replicates the complex functions of the human body**



**Consciousness**
Light sensors in the eyes adjust the pupil size, altering reaction time depending on the condition of the simulated patient.

**Chest sounds**
Speakers in the chest allow medics to listen for irregularities in breathing or heartbeat.

**Genitourinary**
Catheterisation can be practised on the mannequin and on-board fluids even simulate urine flow.

**Body fluids**
Many of the most realistic models contain reservoirs, which produce replica body fluids such as blood, urine and saliva.

**Airway**
Realistic airways enable medics to practise intubation techniques. Some contain a gas analyser to identify the composition of inhaled air.

**Cardiac arrest**
Pressure sensors in the chest mean the mannequin responds to chest compressions.

**Intravenous access**
Veins in the arms allow intravenous drugs to be administered. The program is alerted by a barcode system.

**Circulation**
Mechanical components beneath the skin mimic the feel of pulsing arteries and electronics in the chest generate signals that can be picked up by an ECG machine.

## Types of patient simulators

### Adult
Adult simulators are used in medical and military training. By mimicking the circulatory system and airways, medics can practise emergency techniques so trainees can gain experience in managing life-threatening medical conditions without jeopardising real human patients.

### Baby
Infant medical care is very different to that of an adult, and baby simulators provide specialised training in emergency infant care. The small mannequins allow intravenous injections to be performed and the membranes of the mouth turn blue if the mannequin is starved of oxygen.

### Pregnant mother
These specialist mannequins are used to simulate childbirth and are capable of delivering a baby naturally, or by caesarean. Common medical complications – such as breech birth and postpartum haemorrhage – can all be re-created to enable medics to train for natal emergencies.

### Virtual patients
Some patient simulators are entirely virtual, with no physical representation of the patient at all. These complex computer programs can model huge numbers of biological processes. They do not provide hands-on training, but instead allow scientists to rapidly test new medical hypotheses.

© CAE Healthcare

# THE WORLD OF BIOMETRICS

## How fingerprint scans and other technologies can identify you

In today's connected world, the need to verify our identity comes up countless times each day. Right now, we tend to do that by one of two means: with a physical token like a passport or a door key, or with a piece of knowledge like a password or PIN. But physical ID can be lost or counterfeited, and passwords can be stolen, hacked or simply forgotten.

Enter biometrics. Instead of relying on tokens or knowledge, biometrics uses distinctive measurable characteristics about a person to identify them. Because these are unique to individuals, they make more reliable identifiers, are tough to copy and are impossible to forget. Biometric identifiers are grouped into physiological characteristics, like fingerprints, iris patterns and vein geometry; and behavioural traits, like the way a person types, talks or walks.

Biometric identifications all begin with some form of scan or data collection. This information is then encoded. In the past, this step would be done manually, for example noting the locations of distinctive features in fingerprints, but nowadays computers convert these into numerical code. Finally, these mathematical descriptions get compared to a database in search of a match.

Biometrics can be used in a variety of settings; in national border control or high-security data, website and physical access. It can also monitor who is entering and leaving a workplace or to ensure hospital patients are correctly identified, as well as in law enforcement and security surveillance. Read on to learn about how your unique physical and behavioural characteristics can act as your new password for everything!

**RECORD BREAKERS**
**FINGERPRINTING**

# 129MILLION

## FINGERPRINT ID SPEED RECORD

The number of fingerprints searched in less than one second by the world's fastest automatic identification system – DERMALOG Next Generation AFIS. At ten prints per person, that's more than the entire population of Portugal.

**DID YOU KNOW?** *Four in ten UK secondary schools now use biometric technology as a means of identifying pupils*

## Brain waves

### Great minds think alike, but signal differently

Even when two people think of the same thing, the electrical impulses in their brains differ slightly. Brain-wave biometrics exploits the fact that we all produce distinct patterns of alpha-beta brain waves.

To perform a biometric brain-wave authentication, a user dons a headset that measures their brain activity by means of a single dry-contact sensor on their forehead. Next, they think their 'pass-thought', which is a mental task such as recalling a favourite song or counting objects of a specific colour. Finally, their brain waves are compared with stored recordings of their pass-thoughts to authenticate their identity.

## Gait

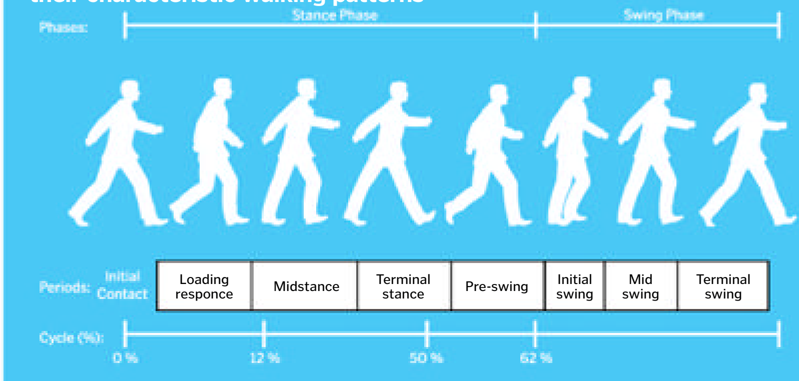
### Although humans share basic movement patterns, gait varies widely from person to person

Ever noticed how you can recognise a friend approaching, before your eyes even focus on the details, just from the way they cut through the crowd? That's because each person's walk – or gait – is unique. Small variations in the lengths of our limbs, the dimensions of our muscles, the angles our joints make, and the complex way our muscles fire in sequence to propel us forward means that each and every one of us has a characteristic lope.

A gait analysis studies a multitude of movement parameters from video footage or sensor information – including a person's walking speed, stride length, step width, the angles of their joints in motion, and how their joints rotate and respond to the varying kinetic forces throughout their stride – and converts this into a mathematical description of a person's walk. Gait analysis is unobtrusive; it requires no physical contact with the subject and can even be done in secret to identify criminals.

## Walk this way

### Gait analysis identifies people based on their characteristic walking patterns



The stance and swing phases are when the lead foot is and isn't in contact with the ground, respectively. The timings of each phase are unique due to your musculoskeletal make-up.

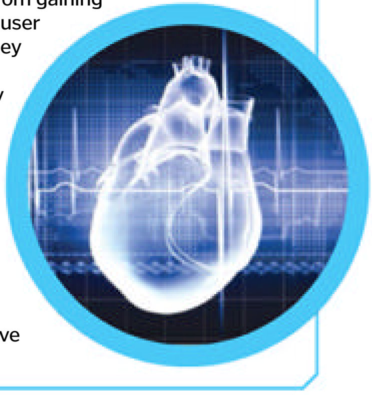
## Heart rhythm

### Forget your memory, all you need is a pulse!

The beat of your own drum – your heart rhythm – is unlike anyone else's. The heart's particular pattern is governed by factors including its shape, size and position in the body. This method could potentially rival a fingerprint for ID authentication purposes, according to the inventors of the Nymi rhythm band.

Cardiac rhythm is monitored using an electrocardiogram (ECG) and is graphically represented as a series of peaks and troughs that correspond to the electrical impulses generated by the heart as it beats. The Nymi wristband continuously compares the wearer's ECG waveform to that of the registered user of nearby devices. If the two match up, the band creates an encryption key, which it transmits to the devices via Bluetooth.

The Nymi makes it possible for devices to recognise their user and prevent imposters from gaining access to them. Wearing it, a user can unlock their devices as they come into close range, automatically sign out as they step away, perform secure transactions by verifying their ID at real-world checkouts, control devices with gestures, and even track their fitness levels. Thankfully, going for a run doesn't alter the characteristic shape of an ECG and age appears to have little effect.



## Vein matching

### No two people have identical veins – not even identical twins!

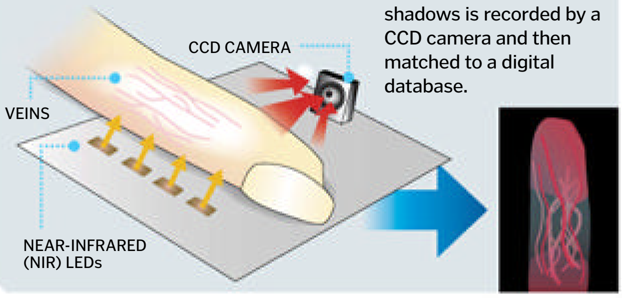
Just like fingerprints, everybody's vein geometry is completely unique and remains the same throughout their lives. Unlike fingerprints, however, vascular patterns are almost impossible to counterfeit because of the vessels' location beneath the skin's surface.

To map a person's veins, their hand or finger is placed into a scanner and illuminated with near-infrared light. A CCD digital camera takes a picture and, because haemoglobin in the blood absorbs the light but the surrounding tissues do not, the veins show up in the picture as black lines. Geometric details such as vein thickness, branching points and branching angles are extracted and mapped for comparison.

## In a similar vein

### Vein matching identifies a person by their unique vascular geometry

The light from a near-infrared light source penetrates the skin and is absorbed by veins but transmitted by other tissues. The pattern of shadows is recorded by a CCD camera and then matched to a digital database.



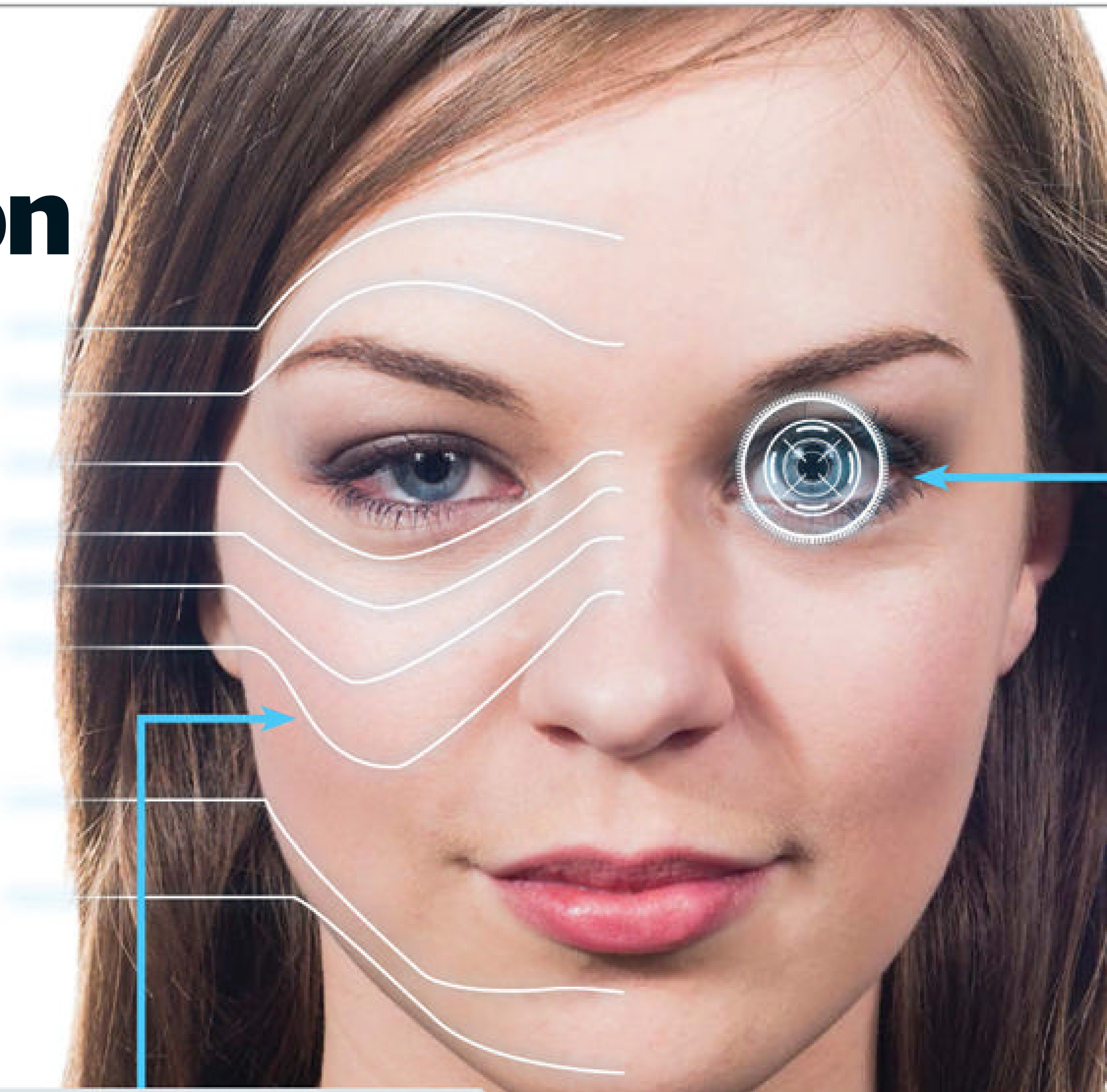
# Facial recognition

## This system identifies our unique facial topography

Humans are exceptionally skilled at recognising and distinguishing faces – there's even a special region of the brain devoted to the task – but computers are quickly catching up. Automatic facial recognition systems analyse the contours of faces to identify individuals from photos, video footage, or 3D surface maps.

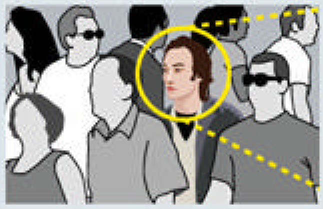
The technology creates a faceprint by measuring and mapping distinguishing features that aren't susceptible to alteration with expression and don't change with age. These include the curve of the eye sockets, the distances between the eyes, nose, mouth and jaw, the width of the nose and the shape of the cheekbones.

Because it can be done covertly and from a distance, facial recognition is useful for surveillance purposes, and 3D systems can even recognise faces in darkness, at angles of up to 90 degrees. The system isn't foolproof though: canny criminals can easily conceal their faces with masks.

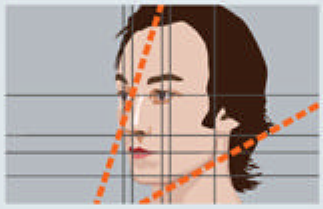


### A face in the crowd

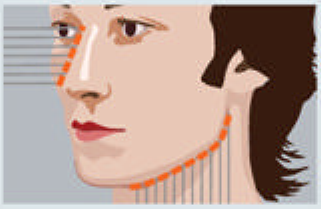
**How facial mapping and matching algorithms can identify you at a distance**



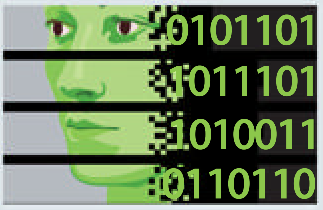
**Detection**
Special software detects the presence of a face in a photograph or video footage.



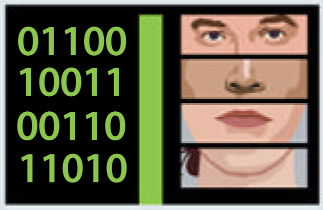
**Alignment**
The software deduces the alignment of the face with respect to the camera.



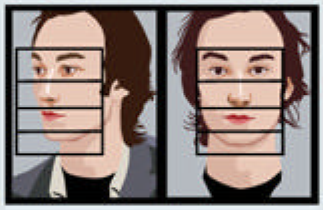
**Measurement**
The curves, ridges and valleys of the face are mapped at a resolution of less than 1mm (0.04in).



**Representation**
Facial feature measurements are digitised so the image can be compared with others in a database.



**Compatibility conversion**
To compare a 3D image with an older database of 2D images, an algorithm converts the source to 2D.

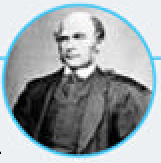


**Matching**
The encoded faceprint image is compared with those stored in a database, seeking a potential match.

## KEY DATES
### BIOMETRIC IDENTIFICATION

**2000 BCE**
Evidence suggests fingerprints were used on clay tablets in transactions in Ancient Babylon.

**1870s**
Alphonse Bertillon's anthropometrics catalogue and identify serial criminals by their body measurements.



**1892**
Sir Francis Galton develops a fingerprint classification system using prints from all ten fingers.

**1994**
The world's first successful iris-recognition algorithm is patented by Dr John Daugman.

**2013**
India's Aadhaar project finishes capturing biometric data of over half a billion residents, making it the world's largest biometric database.

**DID YOU KNOW?** *The Canadian Kennel Club has been accepting dog-nose prints as proof of identity since 1938*

# Iris scanning

### This tech has gone from science fiction to science fact

Iris scanning is underpinned by the fact that no two irises – the textured coloured muscle that regulates the size of your pupil – are identical. They develop randomly in the womb, form fully by eight months of age, and remain stable throughout the rest of a person's life.

During an iris scan, a CCD digital camera takes a high-contrast picture of your eye using both visible and near-infrared light. The iris is located in the image via landmarks including the pupil edge and eyelids, and pattern-recognition software maps the iris's distinct structure of furrows, speckles and ridges.

Iris-recognition systems are among the most accurate of all biometric technologies, and offer more than 200 reference points for comparison (compared to 60 to 70 points in fingerprints). Iris scanning should not be confused with retinal scanning, which compares the patterns of blood vessels on the back of the eye.

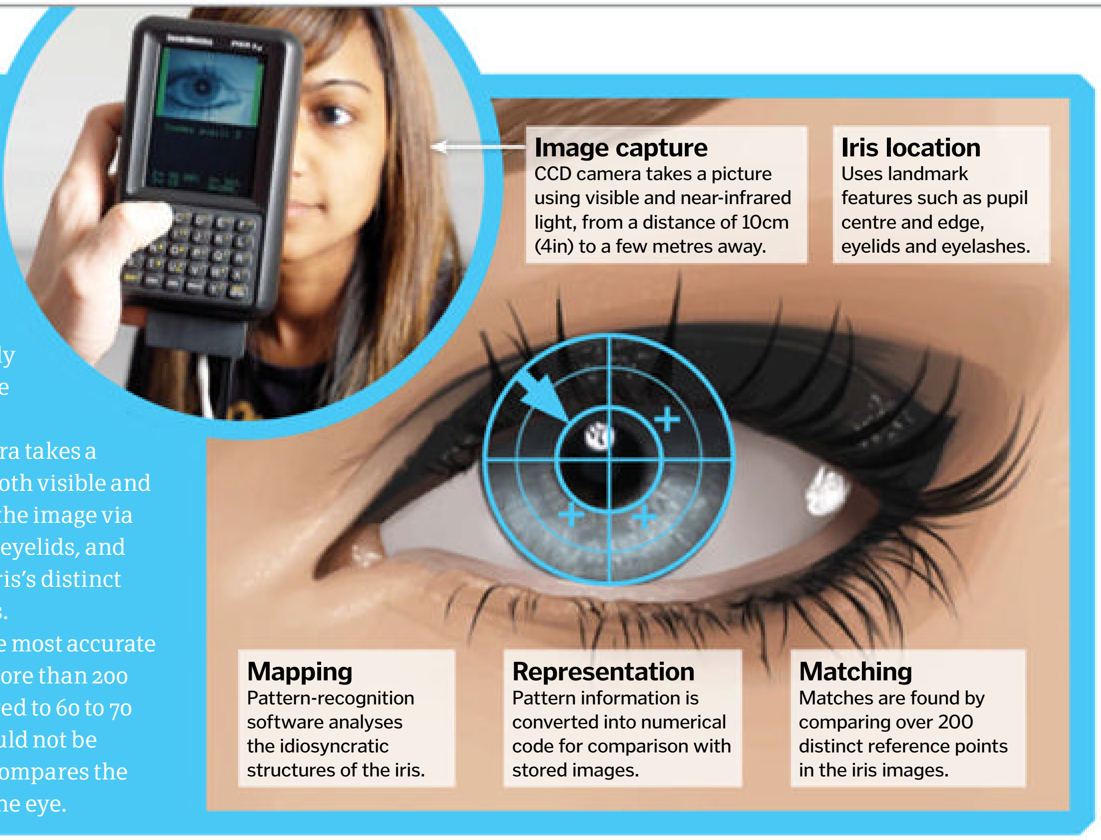


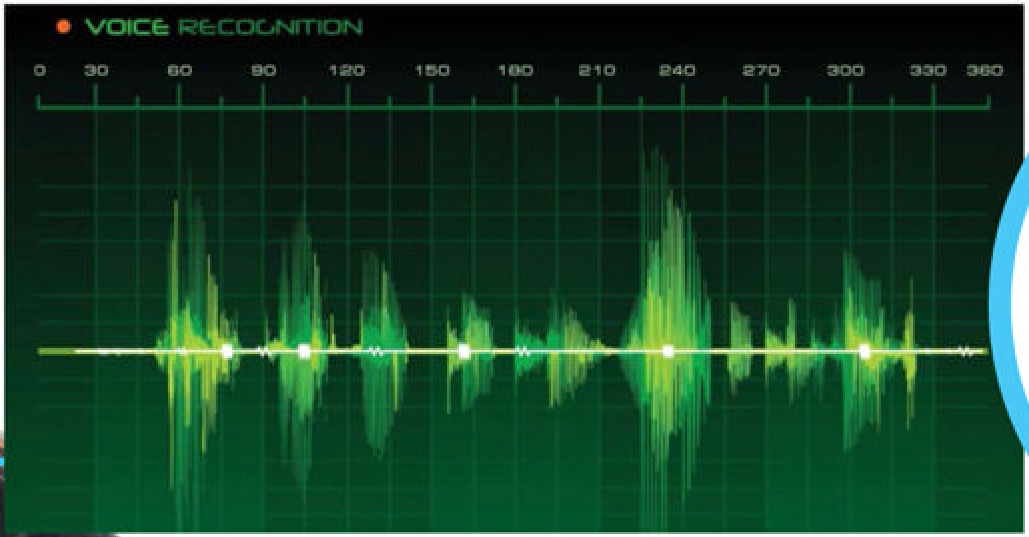
**Image capture**
CCD camera takes a picture using visible and near-infrared light, from a distance of 10cm (4in) to a few metres away.

**Iris location**
Uses landmark features such as pupil centre and edge, eyelids and eyelashes.

**Mapping**
Pattern-recognition software analyses the idiosyncratic structures of the iris.

**Representation**
Pattern information is converted into numerical code for comparison with stored images.

**Matching**
Matches are found by comparing over 200 distinct reference points in the iris images.



# Voice recognition

### You – and your dulcet tones – are a truly singular voice

The sound of your voice is governed by physiological factors – the shape of your vocal tract, airways and surrounding soft-tissue cavities – as well as behavioural factors, linked to personality and peer influence, which affect the motion of your mouth as you speak. Together, these mean that everyone's voice is distinct.

Voice-recognition systems record a spectrogram of how sound frequency varies with time. Qualities like the acoustic characteristics and intensity dynamics of the speaker's voice are extracted and used to identify them.

Simple voice-authentication systems require a person to speak a previously recorded password, but these can be vulnerable if a hacker has a recording of a person saying their password. More advanced systems prompt a user to say a random word and authenticate this against a complete profile of the person's voice.

# Fingerprinting

## How smartphone and airport fingerprint scanners work

Fingerprint identification is the oldest and most widely used biometric method. Our fingerprints – the pattern of loops, whorls and arches – form randomly in the womb and remain unchanged throughout our lives. Like snowflakes, there are infinite pattern possibilities and scientists believe no two fingerprints are ever formed the same way.

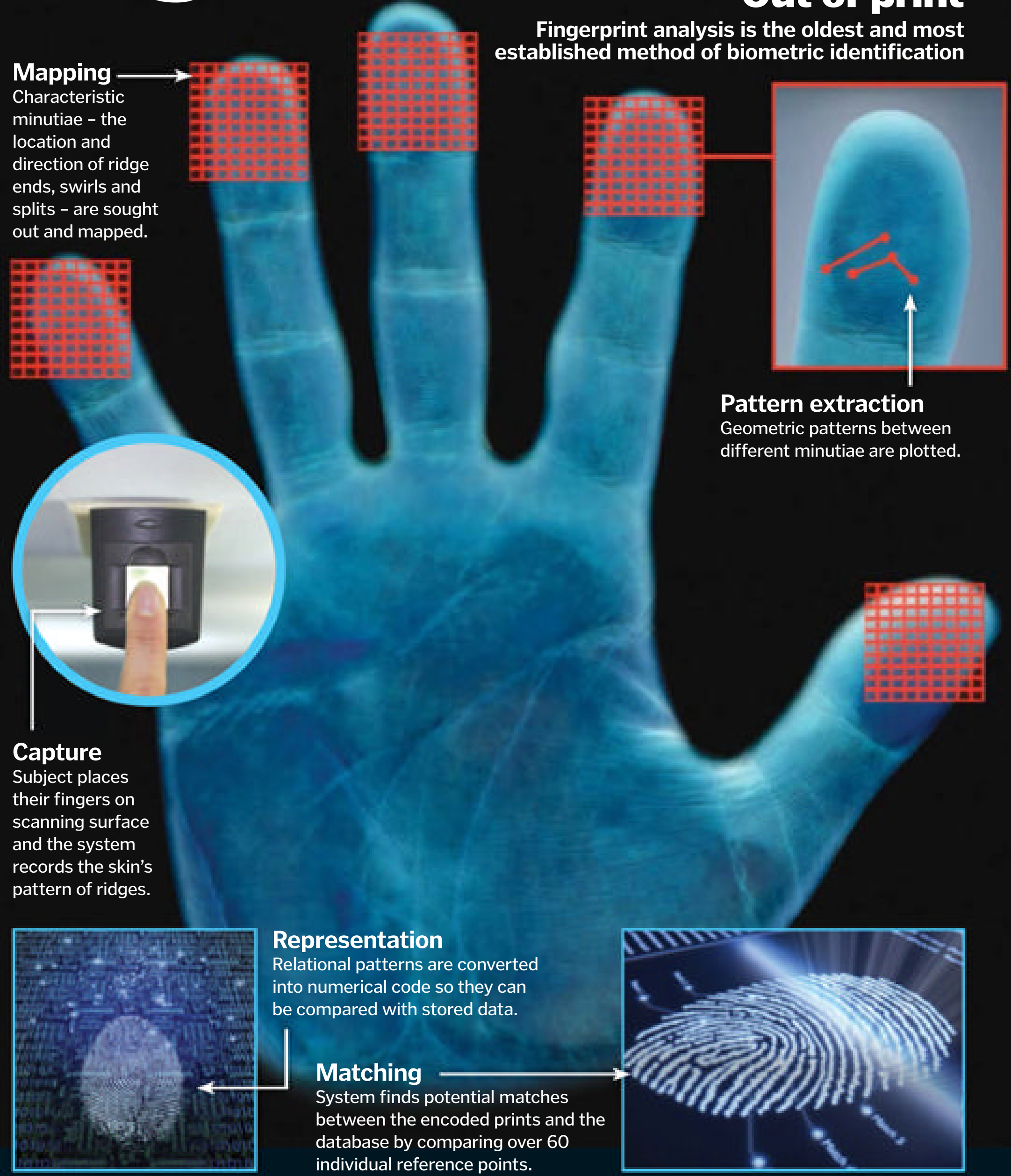
Although there is evidence that fingerprints were used as a person's mark or signature in Ancient Babylon, they have been systematically used to identify people since 1892, when Sir Francis Galton developed a way to classify ten-finger print sets. Galton identified common local features in fingerprints – like where the ridges start, end and split along their paths – which became known as 'Galton Points.'

Galton's legacy lives on in today's fingerprint matching, which uses the location and orientation of a subset of his points, called minutiae. With the advent of computing technology in the 1960s, fingerprint matching became automated. Today, the FBI's IAFIS (Integrated Automated Fingerprint Identification System) – holds over 100 million individuals' prints and performs over 60 million searches on the database per year.

Prints are collected by a variety of means. They can be lifted from a crime scene using fine powder or reactive chemicals, or they can be taken from a person by inking their fingers and stamping them on paper. More recently, they can be captured digitally with a variety of sensors, including optical, thermal and capacitance sensors. Sophisticated computer algorithms analyse the minutiae patterns in the prints and look for matches in a database.

## Out of print

**Fingerprint analysis is the oldest and most established method of biometric identification**



**Mapping**
Characteristic minutiae – the location and direction of ridge ends, swirls and splits – are sought out and mapped.

**Pattern extraction**
Geometric patterns between different minutiae are plotted.

**Capture**
Subject places their fingers on scanning surface and the system records the skin's pattern of ridges.

**Representation**
Relational patterns are converted into numerical code so they can be compared with stored data.

**Matching**
System finds potential matches between the encoded prints and the database by comparing over 60 individual reference points.

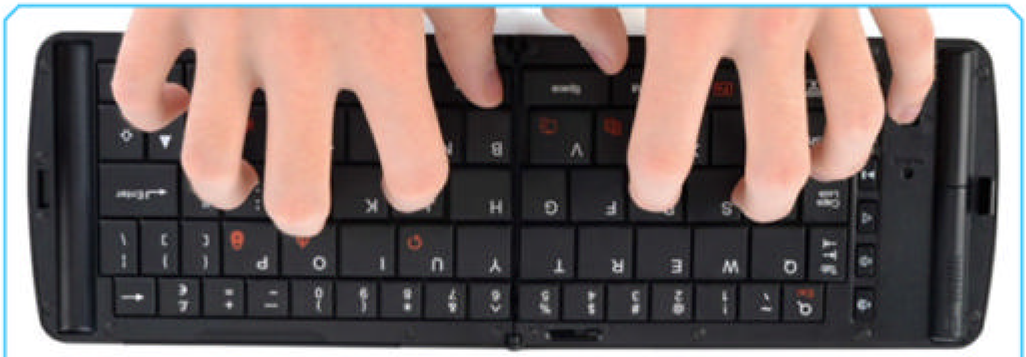
## Are fingerprints really unique?

Fingerprint evidence has been a staple of forensic investigations for over a century and is considered to be conclusive proof of a suspect having been at a crime scene. But some experts contend the underlying principle that no two fingerprints are alike. The predominant patterns in your prints – whorls, loops or arches – run strongly in families and, while evidence suggests it is improbable, proving that no two people have identical prints is practically impossible.

Even if they truly are unique, the collection and identification process can be prone to human error. Crime scene fingerprints can be partial, smudged or degraded, and the exact print left by an individual finger can vary slightly from one impression to the next. Also, humans aren't alone in having fingerprints. Chimps, orangutans and koalas all share the trait and their prints could easily be mistaken for human ones at an interspecies crime scene.

Studies show that even experts are prone to mistakes, coming to different conclusions than their peers and even identifying the same set of prints differently on second glance. This, at least, is one weakness that automated fingerprint identification by computers can banish, reducing the risk of false convictions and unjust punishment.

**DID YOU KNOW?** *The word biometrics derives from the Greek for 'life' and 'measure' and was first used in 1902*



# Keystroke recognition

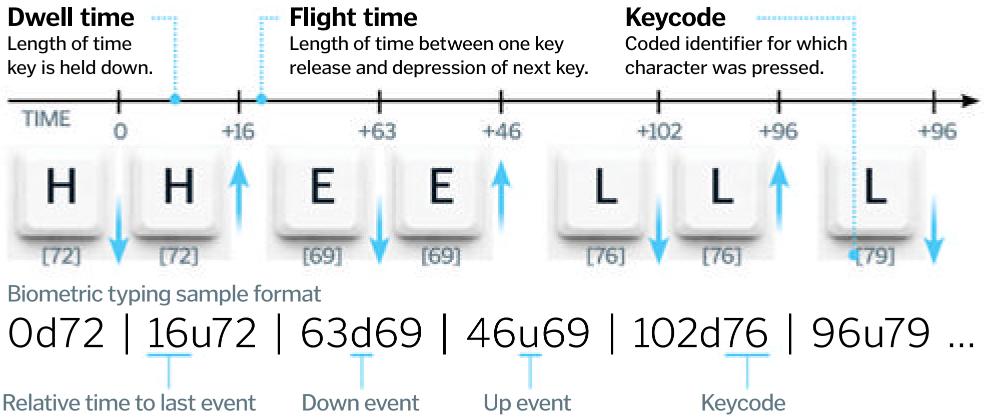
**Your typing rhythm is as distinctive as your handwriting or signature**

Typing rhythms are idiosyncratic because each of us has particular characters that always seem to evade us and certain common letter combinations that fly from our fingers faster than the rest. Keystroke recognition analyses the rhythm and features of a person's typing style by logging nuances like how long they take to reach and depress a key (flight time) and how long they hold keys down (dwell time).

Keystroke-timing data can be collected from any keyboard and compared with stored pattern data to confirm the user is who they claim to be. But the technique is limited by the fact that, even though an individual's typing rhythm is independent of how fast or slow they type, other factors such as how tired they are or whether they have consumed alcohol can interfere with it.

## A certain type

**Keystroke recognition uses your typing rhythms to authenticate your identity**


Dwell time
Length of time key is held down.
Flight time
Length of time between one key release and depression of next key.
Keycode
Coded identifier for which character was pressed.
TIME
0
+16
+63
+46
+102
+96
+96
H
H
E
E
L
L
L
[72]
[72]
[69]
[69]
[76]
[76]
[79]
Biometric typing sample format
0d72 | 16u72 | 63d69 | 46u69 | 102d76 | 96u79 ...
Relative time to last event
Down event
Up event
Keycode

## Biometric passports

**Biometric documents make identity fraud near impossible**

A passport is the ultimate proof of identity. Aside from your birth certificate, it is pretty much the last document you would ever want to be stolen or forged; a thief could wreak all sorts of havoc while assuming your identity, leaving you to deal with the consequences. National border-security agencies need to monitor exactly who enters and leaves their country, a need that, in these times of mass global travel and international terror threats, has become ever-more pressing.

A biometric passport, or e-passport, combines the paper passport of old with a tiny chip and an antenna that allows it to be read electronically. The chip is embedded into a page of the passport in such a way that it can't be tampered with. The chip contains the same basic data as the standard passport information page, plus encrypted digital images of one or more of the holder's biometrics.

When the holder steps up to the immigration window, the relevant biometrics are captured and then compared to those in the passport. All passports now issued in the UK are biometric, and contain information about the holder's face, such as the distances between the eyes, ears, nose and mouth.

## Biometric revolution

**Dr Arun Ross, associate professor of Computer Science and Engineering at Michigan State University, answers our questions on the amazing burgeoning field of biometrics**

**What major advances have been made in biometrics in the last decade?**

**Arun Ross:** First, the matching accuracy of biometric systems has substantially improved. Second, it's now possible to search through large databases of identities very quickly, due to improvements in computational power and development of efficient indexing models. Third, a number of new sensors have been designed. For example, it's now possible to perform iris recognition at a distance.

**What kind of matching accuracies are we talking about?**

**Ross:** That depends on the kind of data you're working on. If you work with mugshots or high-quality fingerprint images, recognition rates can exceed 99 per cent. But if you're dealing with low-quality data from surveillance video, or degraded fingerprints that are lifted from a crime scene, the performance can drop to the 60s.

**Where are biometric identification techniques having the most impact?**

**Ross:** Early systems were mostly used by law enforcement for criminal investigations, but now we're seeing biometrics being incorporated into border security systems and national ID card programs. We're also seeing biometrics enter the consumer electronics market, including smartphones. This is likely to become commonplace as we conduct more and more sensitive transactions online, so the need to verify our identities becomes especially important.

**What are some of the ethical or security concerns surrounding biometric data collection and storage?**

**Ross:** One concern is whether data will be used for purposes outside those expressed at the time of collection – a phenomenon we refer to as function creep. There are also concerns over data theft and misuse. For example, can someone steal my fingerprint as it is being transmitted through cyberspace and play it back for another transaction, or create a fake fingerprint using the stolen data? Legal scholars and biometric researchers are working to see how these security and privacy concerns can be mitigated.

**What developments on the horizon strike you as most exciting?**

**Ross:** Many of us store, access and transmit extremely sensitive information – both personal and professional – using our smartphones, so incorporating biometric solutions into our phones will become important for applications such as online banking. In several countries in Africa, smartphone use is rapidly increasing as access to the internet becomes ubiquitous. Biometrics could be used to great effect there to, for example, verify identities remotely when people use their smartphones to access resources like microloans.

© Dreamstime; The Art Agency; Science Photo Library; Thinkstock; Apple

# Robotic surgery

## Medical technology in the operating theatre has come on leaps and bounds, but it still needs a helping hand from humans…

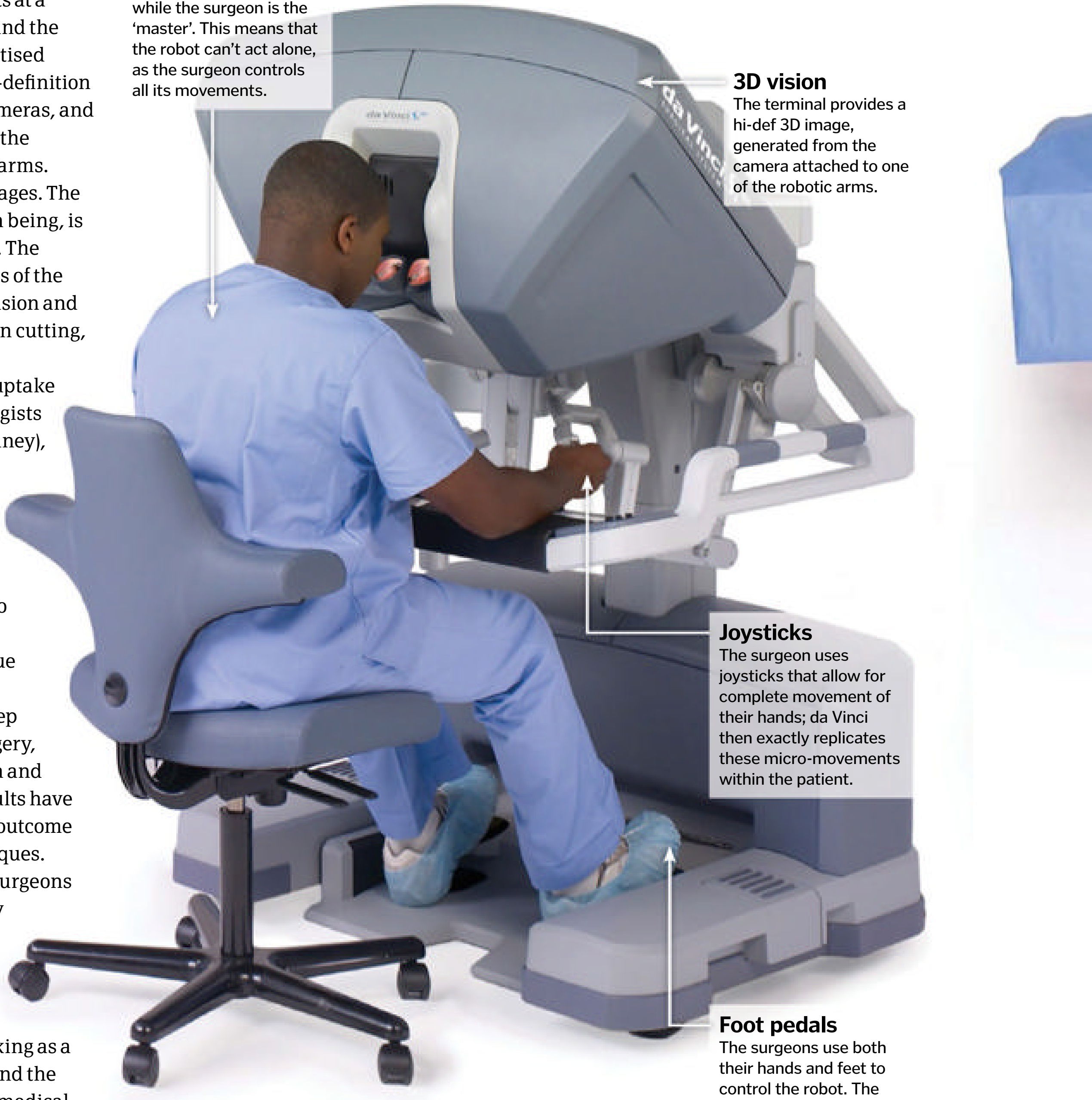
Robotic surgery allows for control and precision previously unknown to surgeons. Contrary to popular belief, the robot does not operate on the patient alone. It is a 'slave' to a human 'master', meaning it is not a true robot (these have intelligence and react automatically). The surgeon sits at a console next to the operating table and the robot is placed around the anaesthetised patient. The surgeon looks at a high-definition 3D image provided by the robot's cameras, and special joysticks are used to control the ultra-fine movements of the robotic arms.

This brings many exciting advantages. The camera, previously held by a human being, is now held perfectly still by the robot. The movements and angles that the arms of the machine provide allow for fine precision and less damage to adjacent tissues when cutting, leading to reduced pain and a faster recovery. This has led to very rapid uptake by some specialists, including urologists (who operate on the bladder and kidney), gynaecologists (who operate on the uterus and ovaries) and heart surgeons. As with most technologies, there are downsides to using robots in operations. They are expensive, large, cumbersome to move into place, and remove the important tactile feeling of real tissue between the surgeon's fingers.

Robotic surgery is considered a step forward from standard keyhole surgery, where the surgeon holds the camera and operating arms. However, early results have shown that there are practically no outcome differences between the two techniques. Combined with higher costs, some surgeons think this means robots are actually inferior to current techniques. This has led to the development of on-going trials, comparing robotic to standard keyhole surgery. Surgeons around the world are working as a single, giant team to deliver these, and the results will determine the future of medical robots for generations to come.

## da Vinci in action

**This state-of-the-art surgical system works as part of a big team to deliver high-precision surgery. Find out what role it plays now…**



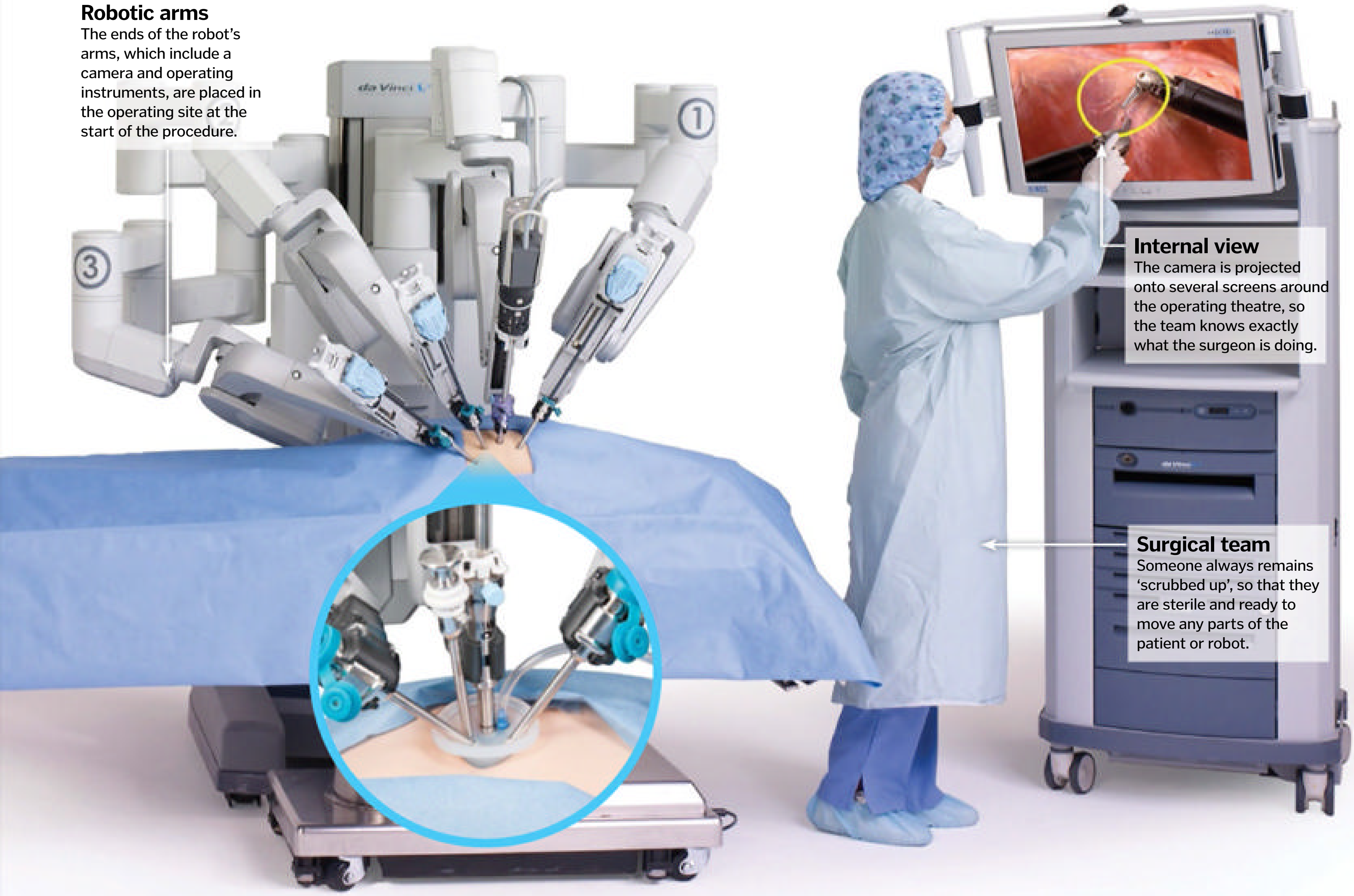
**Human operator**
The robot is the 'slave', while the surgeon is the 'master'. This means that the robot can't act alone, as the surgeon controls all its movements.

**3D vision**
The terminal provides a hi-def 3D image, generated from the camera attached to one of the robotic arms.

**Joysticks**
The surgeon uses joysticks that allow for complete movement of their hands; da Vinci then exactly replicates these micro-movements within the patient.

**Foot pedals**
The surgeons use both their hands and feet to control the robot. The foot pedals help move the camera's position.

**DID YOU KNOW?** *Surgical robots are incredibly expensive, with current versions costing around £900,000 [$1.45mn] each*



**Robotic arms**
The ends of the robot's arms, which include a camera and operating instruments, are placed in the operating site at the start of the procedure.

**Internal view**
The camera is projected onto several screens around the operating theatre, so the team knows exactly what the surgeon is doing.

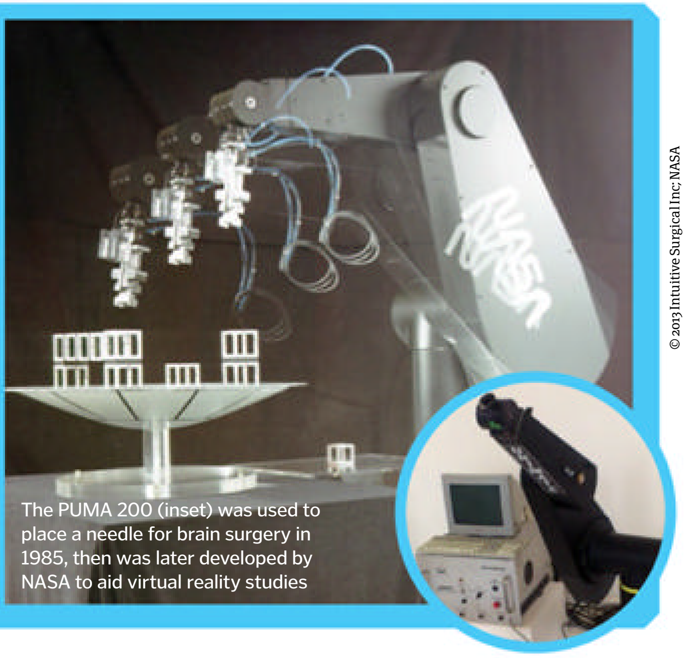
**Surgical team**
Someone always remains 'scrubbed up', so that they are sterile and ready to move any parts of the patient or robot.

## Fluorescence imaging

Fluorescence imaging is still in the experimental stages, and is right at the cutting edge of technological science. Indocyanine green (ICG) is a dye that was initially developed for photography and is now used clinically. It is injected into the patient's bloodstream, and has been adapted so that it sticks to cancer cells – for example, within the bowels. At the time of surgery, the doctor inserts a camera into the patient's body (either using their hands or a robot), and the dye is excited by light at a precisely matching wavelength. This creates bright green fluorescence, distinguishing cancerous from normal tissue and allowing the surgeon to make precise incisions.

## The evolution of robotic surgery

The current robots in use, like the da Vinci Surgical System, are second generation. The first generation, like the Unimation PUMA developed in the Eighties, had very limited movements and could only carry out specific tasks. The second generation brought a range of fine and varied actions, which surgeons rapidly adapted to. These new-and-improved robots were pioneered and driven forward by North American health systems. Uptake has been slower in Britain due to health budgets, at a time when other treatments have an even bigger impact on patient outcome. There is excitement over development of the third generation of robot, which promises to be more compact, faster and to be packing in even more cutting-edge technology. The future may see telesurgery, where the surgeon in one place (eg a hospital) performs robotic surgery on a patient elsewhere (eg an injured soldier on a battlefield).



The PUMA 200 (inset) was used to place a needle for brain surgery in 1985, then was later developed by NASA to aid virtual reality studies

© 2013 Intuitive Surgical Inc; NASA

# A cornea-reshaping lens

## Sleeping with this special contact lens can correct near-sightedness

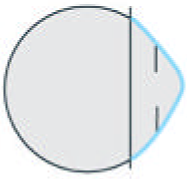
Sick of spectacles? Can't handle contact lenses? There's now a way to correct your vision; orthokeratology. This method involves a type of gas-permeable contact lens that reshapes your cornea while you sleep. When you wake up, you remove the lenses and your vision is 20/20 for the day. This will last for a few days until your eyes' corneas return to their natural shape, but you can repeat the process.

The procedure, which is also known as corneal refractive therapy, is most effective for people with mild myopia (near-sightedness), hyperopia (far-sightedness) and astigmatism. 'Ortho-K' can also help correct or prevent the onset of presbyopia, where the eye's ability to focus on close objects is diminished. As well as being a day-to-day treatment, it can be used to slow the onset of near-sightedness in children.

Orthokeratology is primarily designed for people who do not qualify for laser eye surgery. The reshaping of the cornea is only temporary, so there is very little risk for the eye. The surface of the eye is measured by a corneal topographer, which maps the cornea so the corrective lens can be moulded in the right shape. In some patients 20/20 vision isn't possible, but 20/40 – usually the legal limit for diving – is the aim point for the majority of procedures.

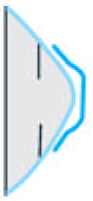
## Corneal refractive therapy

**What happens to your eye overnight**



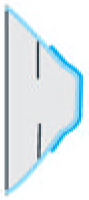
### Diagnosis

Your near or far-sightedness may be due to your cornea being the wrong shape. This is where orthokeratology comes in.



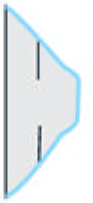
### Fitting the lens

The lens is put onto your eye just like a standard contact lens. You wear it as you snooze and take it out the following morning.



### Correction

The cornea in each eye will adjust into a new mould overnight to give you better eyesight. It is a completely painless process.

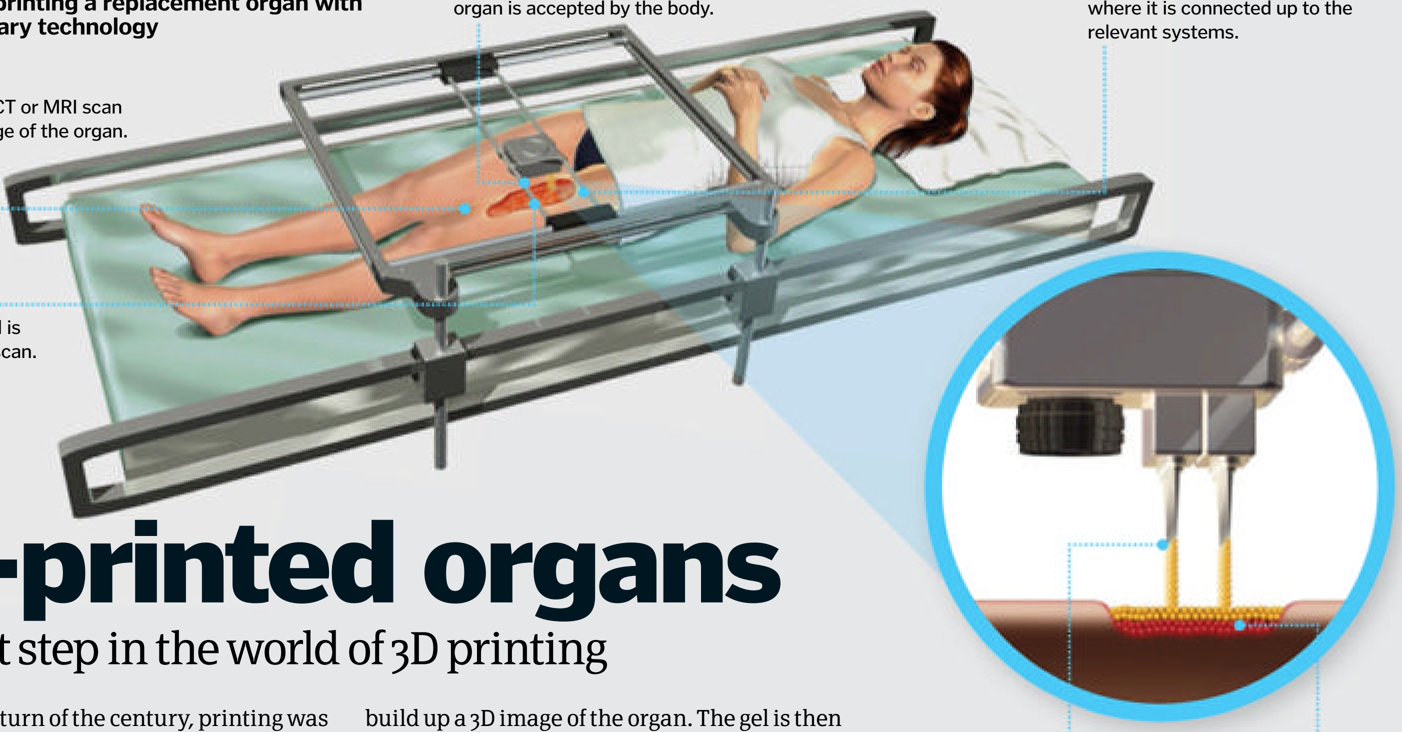


### The next day

The following morning your sight will have improved. Lasting for a few days, the process can be repeated for extended effect.

## How to 3D print an organ

**The stages of printing a replacement organ with this revolutionary technology**



**Scan**
The patient has a CT or MRI scan to build up an image of the organ.

**Model**
A computer model is created from the scan.

**Acceptance**
Doctors then wait to see if the organ is accepted by the body.

**Implant**
The organ is placed into the body where it is connected up to the relevant systems.

**Printing**
The organ is printed using human cells and a sticky gel that binds it together.

**Gel removal**
The gel gets washed away, leaving just the cells in the shape of the organ.

© SPL; Thinkstock

# 3D-printed organs

## The next step in the world of 3D printing

At the turn of the century, printing was limited to words and pictures on a page. Now, in less than two decades, we are on the cusp of being able to print human organs. Patients are sent for a CT or MRI scan that maps out the organ that needs to be printed. A digital model is then created in a computer. The printer uses human cells mixed with a gel to build up a 3D image of the organ. The gel is then removed, leaving just the cells. This would then be implanted into the patient. There are still many challenges to overcome in 3D printing organs, such as creating arteries, veins and capillaries, but the day we can replace a person's liver, kidney or even heart with a 3D-printed organ seems to be creeping ever closer.

# Taking photos in the body

## How do we capture images from inside the human digestive system?

An endoscopy is any operation involving the study of the inner workings of the human body. Traditionally, an instrument called an endoscope is used, but more recently tiny cameras inside capsules we can swallow have been taking their place. Specialising in the inspection of the intestines, oesophagus and stomach, it can examine places the endoscope could never reach. In particular, it studies the three major sections of the small intestine: the duodenum, jejunum and ileum.

About the size of a pound coin, the capsule transmits images to outside data recorders. It moves naturally through the digestive tract and is designed to help diagnose the causes of chronic diarrhoea, inflammatory bowel disease, abdominal pain and malabsorption.

To capture images, the mechanism shines a light from its LED source onto the wall of any part of the gastrointestinal tract. These images are then transported by radio waves to a nearby receiver or monitor for analysis.

If there's a downside, it is that currently the camera can't be stopped to take a closer look at anything, as it's moved by natural peristalsis.

To date, over 400,000 procedures have been performed worldwide and retention has occurred in only 0.75 per cent of cases, so the chances of it not passing through safely are very slim. In around eight hours the capsule can capture an incredible 50,000 or so images.

It costs about £600 ($1,000) to administer but its ability to explore parts of the digestive system in unprecedented detail – outside invasive surgery – is invaluable.

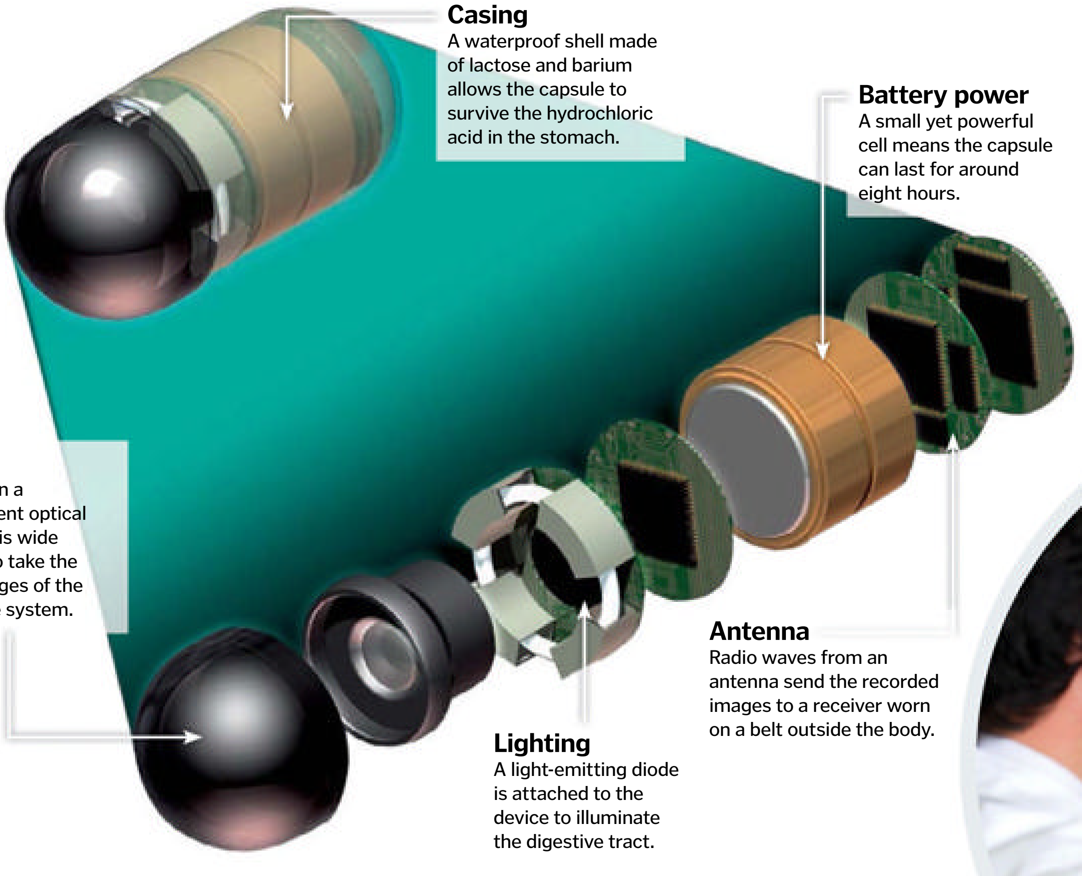
### Nil by mouth

Camera capsule endoscopy is a painless and relatively fast process. To allow the procedure to work effectively, the patient must observe a few important measures. Prior to examination, the patient must not eat or drink anything for 12 hours. In some cases, patients may also need to cleanse their bowel before the procedure takes place. After taking the capsule, you can move around as long as you don't make any sudden movements. The vast majority who have used the capsule said they felt no pain or discomfort. You can drink clear liquids two hours after ingestion and eat food after about four hours.

Images can be instantly transmitted to a computer for closer analysis

## The camera in a pill

**What technology makes up this inner-body explorer?**



**Casing**
A waterproof shell made of lactose and barium allows the capsule to survive the hydrochloric acid in the stomach.

**Battery power**
A small yet powerful cell means the capsule can last for around eight hours.

**Lens**
Housed in a transparent optical dome, it is wide angled to take the best images of the digestive system.

**Antenna**
Radio waves from an antenna send the recorded images to a receiver worn on a belt outside the body.

**Lighting**
A light-emitting diode is attached to the device to illuminate the digestive tract.

© Rex Features; Corbis; DK Images

# EXO SUITS

## THE FUSION OF MAN AND MACHINE WAS THOUGHT THE STUFF OF SCIENCE FICTION, UNTIL NOW

*Iron Man* is no longer the sole domain of comic books and film superheroics. Thanks to advanced robotics and human-machine interfaces, mechanised exoskeletons are being adopted worldwide. From machines capable of turning men into super-soldiers to cyborg implants clever enough to make the disabled mobile, the concept of human augmentation is rapidly transitioning from pipe dream to power on, with a host of companies and developers producing systems to make humans quicker, stronger and more perceptive.

Why is this revolution happening now? It's a combination of advanced discussion regarding the ethics of such augmentations by the Earth's brightest minds and a ravenous, insatiable drive by science and technology corporations to take humanity into a glorious new age. Before, scientific developments such as these would have been stamped out by fanatics, now if a person is born without the use of their legs they will still be able to walk and live their life like they never thought possible.

Strap yourself in and power up your mind as **How It Works** takes you on a tour through some of the most groundbreaking advancements changing the world in the fields of robotics and bionics. Welcome to the human-machine fusion revolution.

PROSTHESIS

**RECORD BREAKERS**
**GOING DEEPER**

# 1,000ft

## DEEP DIVING SUIT

A 240kg (530lb) deep-sea diving suit called the Exosuit, a next-generation Atmospheric Diving System (ADS), has enabled scientists to explore the ocean as far as 305m (1,000ft).

**DID YOU KNOW?** *The first prototype for the Hybrid Assistive Limb (HAL) was built in 1997*

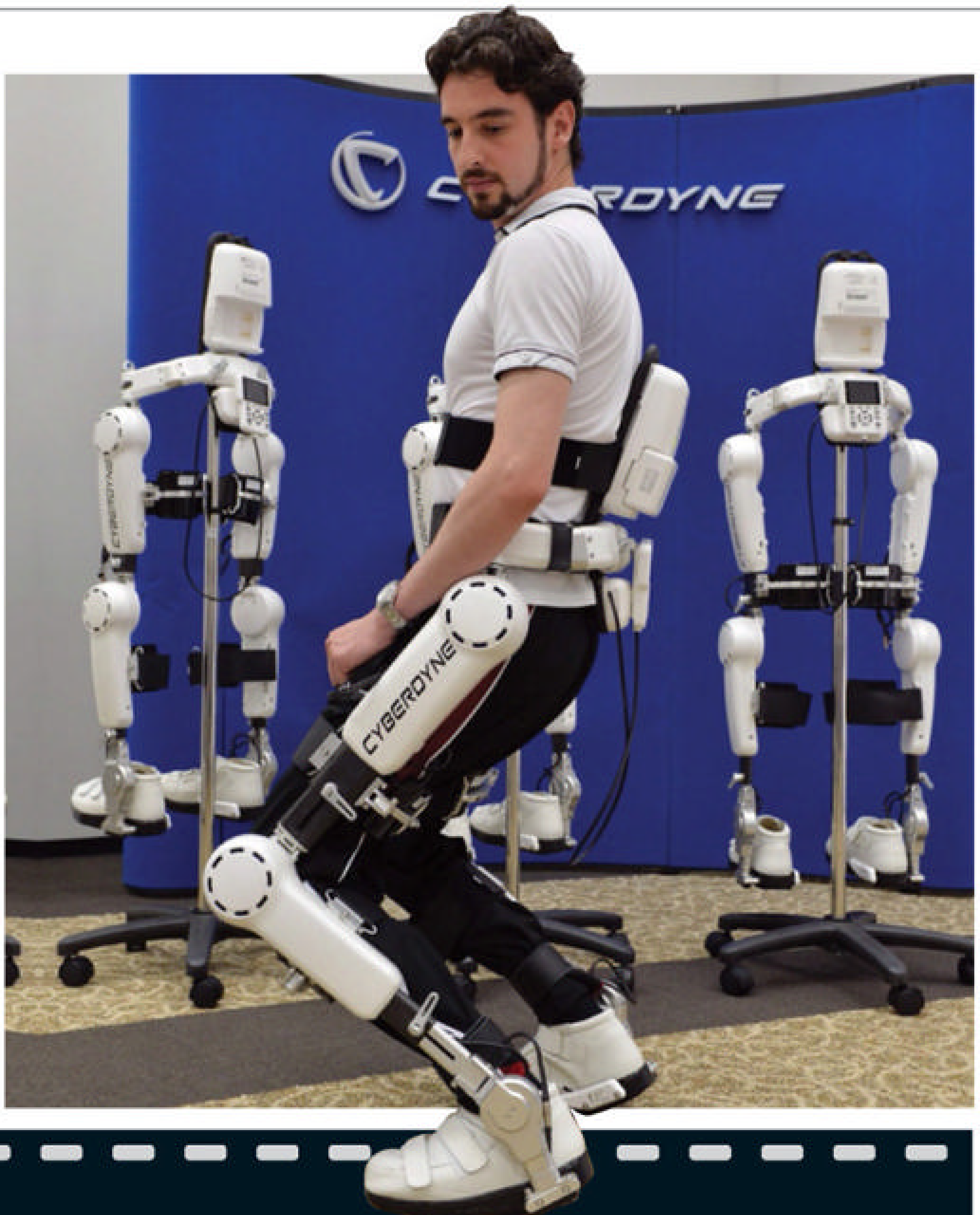
# HAL

## *HUMAN LIMBS EVOLVED*

One of the most useful developments in human augmentation right now is Cyberdyne Inc's Hybrid Assistive Limb, codenamed HAL. HAL is the world's first cyborg-type robotic system for supporting and enhancing a person's legs, giving them the ability to walk if disabled.

Attached to the user's lower back and legs, HAL works in a five-step process. The user merely thinks about the motions they want to undertake, such as walking. This causes the user's brain to transmit nerve signals to the muscles necessary for the motion to take place. At this stage, a disabled user wouldn't be able to receive these nerve signals correctly in their limb muscles, but with HAL attached, they can. HAL is able to read the user's emitted bio-electric signals (BES), faint subsidiary signals from the brain-muscle signals that extend to the surface of the user's skin. By detecting these signals, HAL is then able to interpret the motion intended by the user and execute it, allowing them to move.

What is most exciting about HAL is its potential to train disabled individuals to move without its help. That is because every time HAL helps its user move, a natural feedback mechanism sees the user's brain confirm the executed movement, training the user's body to transmit those nerve signals correctly. While still some way off, continued development could eventually see HAL train a disabled person to walk unassisted.

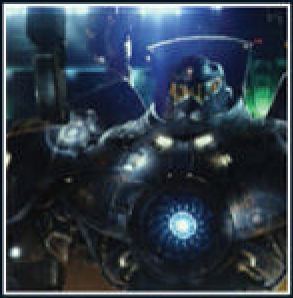


## Top 5 movie mechs

### Gipsy Danger

*Pacific Rim (2013)*

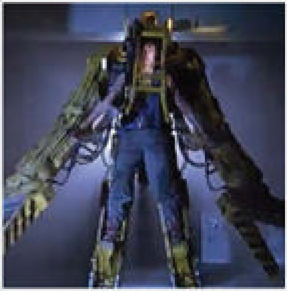
One of the most important mechs from 2013's *Pacific Rim*, Gipsy Danger helps humanity combat inter-dimensional beasts bent on Earth's destruction.



### Power Loader

*Aliens (1986)*

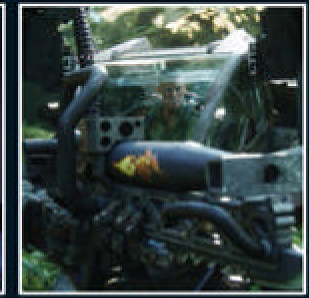
Piloted by Ripley in James Cameron's *Aliens*, the Power Loader mech helps Sigourney Weaver's feisty protagonist face off against the fearsome alien queen.



### AMP

*Avatar (2009)*

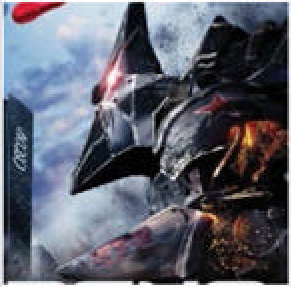
Another hot mech from the mind of James Cameron, *Avatar*'s AMP plays a key role in the film's finale, with the baddie wreaking a whole lot of havoc in one.



### Rhino

*The Amazing Spider-Man 2 (2014)*

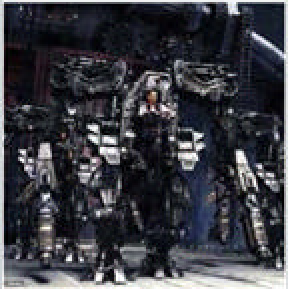
Russian mobster Aleksei Sytsevich breaks out of prison and tears up Manhattan in a mech suit inspired by a rhinoceros.



### APU

*The Matrix Revolutions (2003)*

Protecting the remnants of humanity against the sentinels of the *Matrix* universe, the APU deals huge damage with big guns.



No longer the sole domain of comics and movies like *GI Joe*, exoskeletons are helping soldiers in the field

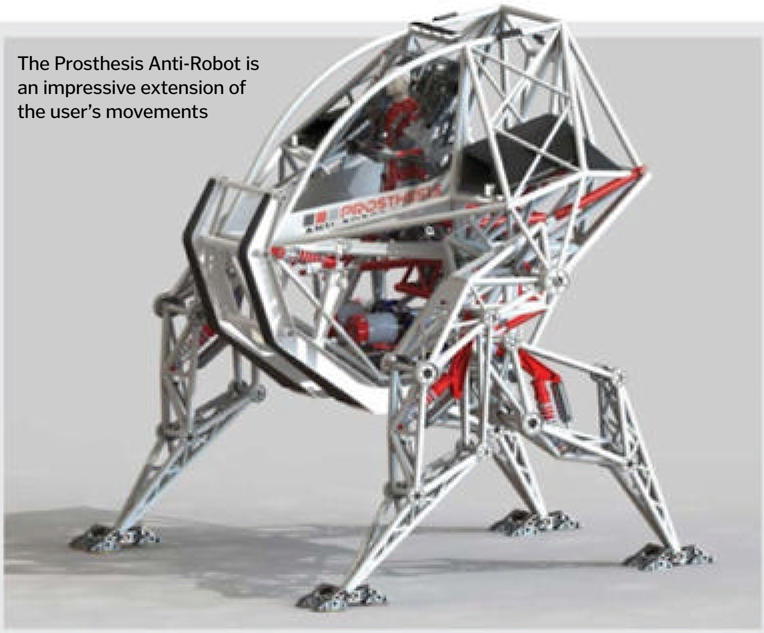
# HULC

### FASTER, STRONGER, TOUGHER

While Cyberdyne Inc's HAL is helping disabled people move once again, Lockheed Martin's HULC Exoskeleton is transforming able-bodied soldiers into mechanised warriors capable of feats of strength, speed and endurance never before seen by humans.

A hydraulic exoskeleton, the HULC allows soldiers to perform superhuman feats such as carrying loads of 90 kilograms (200 pounds) over difficult terrain for hours on end, all the while retaining maximum mobility. It achieves this by augmenting the soldier with a pair of powered titanium legs and a computer-controlled exoskeleton with a built-in power supply. This mechanism transfers the weight carried by the soldier into the ground, while providing power for continued, agile movement in the theatre of war.

Due to the HULC's advanced composite construction and build materials, it also acts as armour for its user, protecting them from musculoskeletal injuries caused by stress from carrying heavy loads. Indeed, when you consider that HULC may also improve metabolic efficiency in its user, reduce oxygen consumption and improve the rate of muscle wear, its hard not to see the future of frontline combat becoming reliant on these mech warriors.



The Prosthesis Anti-Robot is an impressive extension of the user's movements

# RACING BOT

### THE ULTIMATE PROSTHESIS

The Prosthesis Anti-Robot is a towering machine operated purely by human body movements. If that doesn't impress you, how do you feel knowing the Anti-Robot weighs over 3,400 kilograms (7,500 pounds) and is 4.6 metres (15 feet) tall?

The pilot can move such a huge machine by their own efforts thanks to an interface that attaches to their arms and legs and translates the movements of their limbs into the robot's four hydraulic legs. This, along with positional and force feedback, means the pilot's limbs directly correlate to those of the machine and when the force on them increases, the limbs get harder to move. A suspension system also helps the pilot feel when the bot's feet connect with the ground.

The Anti-Robot clearly highlights the possibilities of exoskeletons, with human strength and speed not only dramatically increased but also transferred into a machine many times their size. It's not hard to foresee construction workers suited up and shifting huge crates with ease in the near future.

## The rise of the mechs

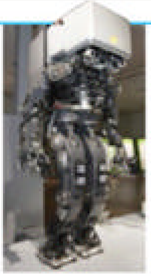
**A timeline of real-life robotic tech**

**1961**
Jered Industries in Detroit creates the Beetle, a tracked mech tank weighing 77 tons. The pilot is shielded by steel plating.

**1968**
General Electric creates the first cybernetic walking machine, a piloted mech with hydraulic hands and feet.

**1989**
MIT creates Ghengis, a small robot insect capable of scrambling over rough terrain while remaining stable.

**1993**
Honda unveils its first humanoid robot, the P1, which can walk around on two feet while tethered. It evolves into the now-famous ASIMO.



**2000**
DARPA, the US Defense Advanced Research Projects Agency, requests proposals for a powered military exoskeleton. It chooses the Sarcos XOS.

**THE STATS**
**PROSTHESIS ANTI-ROBOT**

| HEIGHT | WIDTH | LENGTH | MASS | STRIDE LENGTH | MAX SPEED |
|---|---|---|---|---|---|
| 5m | 4.9m | 3.3m | 3,400kg | 4.5m | 30km/h |

**DID YOU KNOW?** *The Prosthesis Anti-Robot project is a 100 per cent volunteer-staffed project*

## BIONIC WALKER

### SUIT UP!

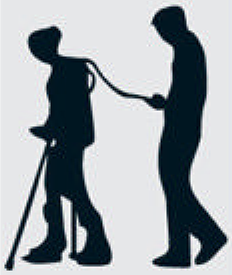
The most advanced gait-training exoskeleton currently in use, the Ekso Bionic Suit has been specially designed to grant people with paralysis a means of standing and walking. Once wearing the Bionic Suit, those who have suffered from neurological conditions such as strokes, spinal cord damage or traumatic brain injury can re-learn correct step patterns and weight shifts – things that able-bodied humans take for granted – all the while supported by a system that assists when needed and records every movement for later analysis.

The Bionic Suit already has an shining record, with every medically cleared user walking in the suit in their first training session. Fitting the suit takes just five minutes so doctors can treat multiple patients, with the suit simply affixed over a user's normal clothes. Considering that it also offers multiple training modes, progressing its wearer from being unable to walk right through to various motor levels, and that Ekso has only been in operation since 2005, it's easy to see how the technology could transform lives.

## Walking modes

### First steps

A physical therapist controls the user's steps with button pushes, with the wearer supporting themselves with crutches.

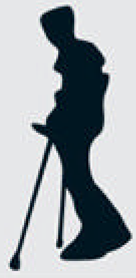


### Active steps

In the second stage, the user takes control of their limb movements through button pushes on a set of smart crutches.

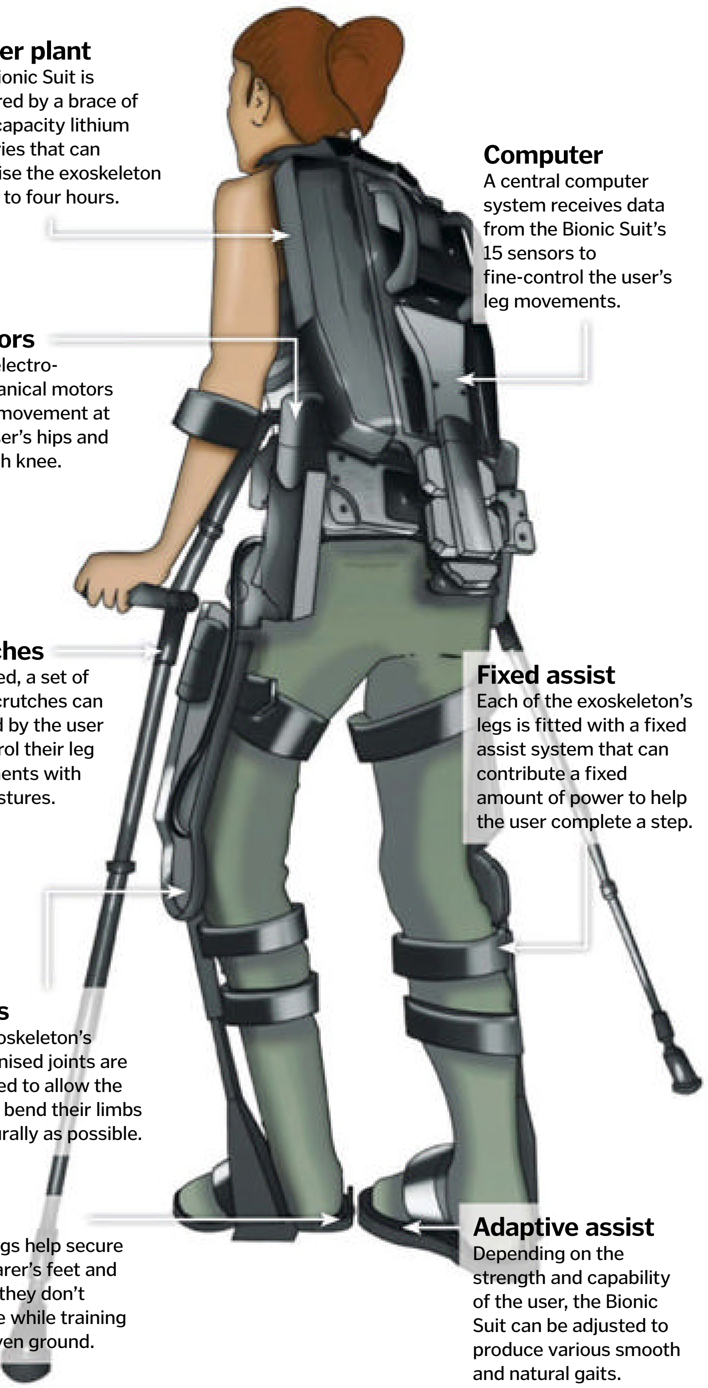
### Pro steps

In the most advanced stage, the exoskeleton moves the user's hips forward, shifting them laterally into the correct walking position.



## Anatomy of the Ekso Bionic Suit

**Check out the core components and features of this revolutionary exoskeleton**



**Power plant**
The Bionic Suit is powered by a brace of high-capacity lithium batteries that can energise the exoskeleton for up to four hours.

**Computer**
A central computer system receives data from the Bionic Suit's 15 sensors to fine-control the user's leg movements.

**Motors**
Four electro-mechanical motors drive movement at the user's hips and at each knee.

**Crutches**
If needed, a set of smart crutches can be used by the user to control their leg movements with arm gestures.

**Fixed assist**
Each of the exoskeleton's legs is fitted with a fixed assist system that can contribute a fixed amount of power to help the user complete a step.

**Joints**
The exoskeleton's mechanised joints are designed to allow the user to bend their limbs as naturally as possible.

**Pegs**
Heel pegs help secure the wearer's feet and ensure they don't stumble while training on uneven ground.

**Adaptive assist**
Depending on the strength and capability of the user, the Bionic Suit can be adjusted to produce various smooth and natural gaits.

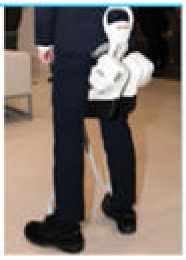
**2004**
TMSUK and Kyoto University reveal the T-52 Enryu, one of the first rescue robots to be used by Japanese emergency services.

**2006**
Japanese machinery and robotics manufacturer Sakakibara-Kikai produces the first genuine bi-pedal mech. The machine measures a huge 3.4m (11.2ft) tall.

**2009**
Lockheed Martin reveals its Human Universal Load Carrier (HULC), an exoskeleton purpose-built to be worn by US soldiers.

**2011**
Rex Bionics launches the Rex exoskeleton, a device that consists of a pair of robotic legs that can help people with paraplegia to stand and walk.

**2013**
Honda begins US trials of its Walking Assist Device at the Rehabilitation Institute of Chicago. The product aims to help stroke patients walk again.

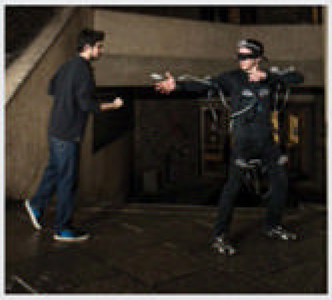


## Real-life spidey sense

Ever thought it would be cool to have the 'spidey sense' of *Spider-Man* in real life? Well, now you can, thanks to a neat research project undertaken by the University of Illinois. SpiderSense is a wearable device that, by manipulating the some of the millions of sensory receptors located on human skin, can relay information about the wearer's environment to them. This clever tech means that despite being blindfolded, the user would know exactly where they were in relation to moving objects.

The system works thanks to the SpiderSense's wearable tactile display, which consists of a series of sensor modules affixed to the user's arms and legs. As the user moves about a room, distance information regarding its objects are relayed to the user through the pads via increases or decreases in pressure, with the skin's receptors relaying that information to the brain. The sensor modules scan the environment using ultrasound, repeatedly sweeping an environment for objects and barriers in the way.

In terms of applications, technology like SpiderSense could be used to compensate for a dysfunctional or missing sense, such as visual impairment, or to augment someone's fully functional senses.

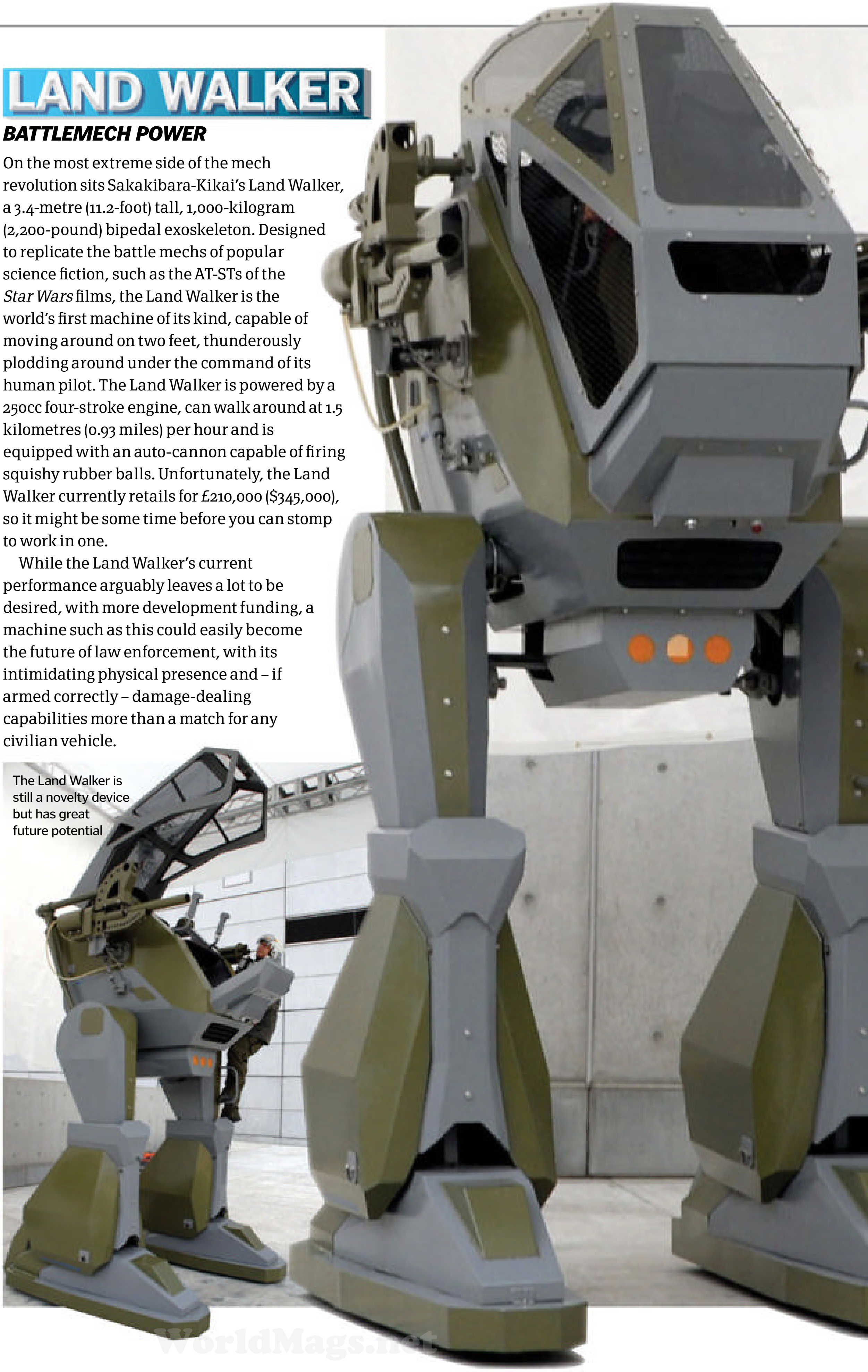


# LAND WALKER

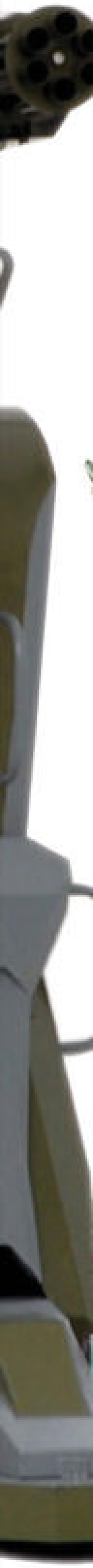
### BATTLEMECH POWER

On the most extreme side of the mech revolution sits Sakakibara-Kikai's Land Walker, a 3.4-metre (11.2-foot) tall, 1,000-kilogram (2,200-pound) bipedal exoskeleton. Designed to replicate the battle mechs of popular science fiction, such as the AT-STs of the *Star Wars* films, the Land Walker is the world's first machine of its kind, capable of moving around on two feet, thunderously plodding around under the command of its human pilot. The Land Walker is powered by a 250cc four-stroke engine, can walk around at 1.5 kilometres (0.93 miles) per hour and is equipped with an auto-cannon capable of firing squishy rubber balls. Unfortunately, the Land Walker currently retails for £210,000 ($345,000), so it might be some time before you can stomp to work in one.

While the Land Walker's current performance arguably leaves a lot to be desired, with more development funding, a machine such as this could easily become the future of law enforcement, with its intimidating physical presence and – if armed correctly – damage-dealing capabilities more than a match for any civilian vehicle.



The Land Walker is still a novelty device but has great future potential



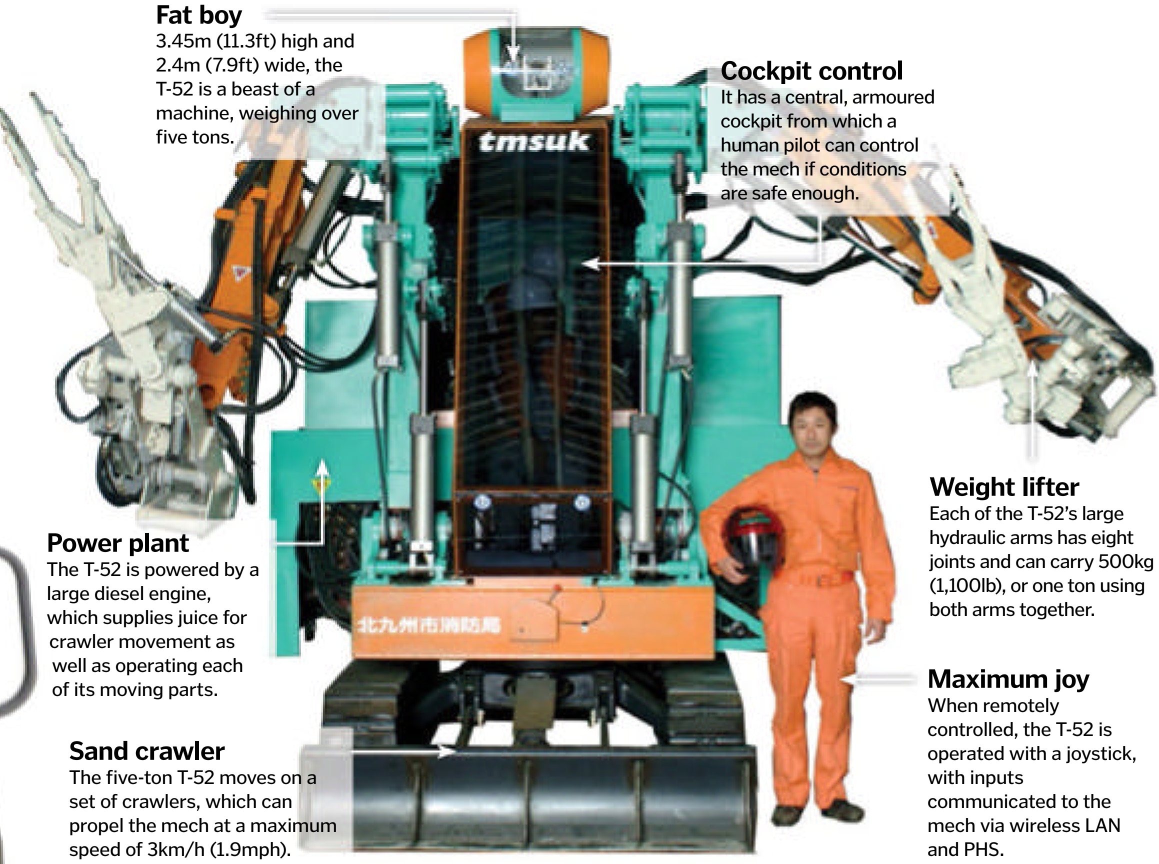
# ENRYU

## *ROBOTIC RESCUE DRAGON*

A large-scale, human-controlled robot for use in disaster sites, the T-52 Enryu (which translates as 'T-52 Rescue Dragon') is one heck of a piece of kit. At 3.45 metres (11.3 feet) tall and 2.4 metres (7.9 feet) wide, it's packed with seven 6.8-megapixel CCD cameras and the ability to lift objects weighing up to one ton with its hydraulic arms. The T-52 is arguably the most advanced disaster-relief mech in service, infiltrating hazardous areas and withstanding conditions a human never could.

The mech was built by the Japanese company TMSUK in partnership with Kyoto University and Japan's National Research Institute of Fire and Disaster for undertaking heavy-duty work in disaster areas. The T-52 can either be operated from its armoured cockpit or remotely from a control station, with the pilot receiving contextual information via a series of LCD displays.

The machine specialises in lifting large and heavy objects, meaning that it can easily help free people trapped in earthquake-generated building collapses. While the Rescue Dragon is still in its development phase, it has already passed a number of operational tests and was recently deployed to help clear up the Fukushima Daiichi nuclear plant disaster of 2011, patrolling the site and removing large pieces of radioactive rubble.



**Fat boy**
3.45m (11.3ft) high and 2.4m (7.9ft) wide, the T-52 is a beast of a machine, weighing over five tons.

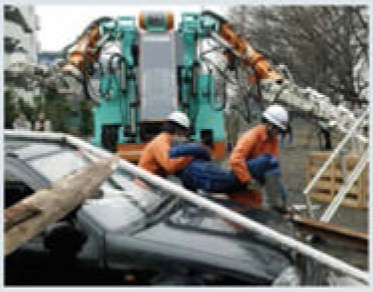
**Cockpit control**
It has a central, armoured cockpit from which a human pilot can control the mech if conditions are safe enough.

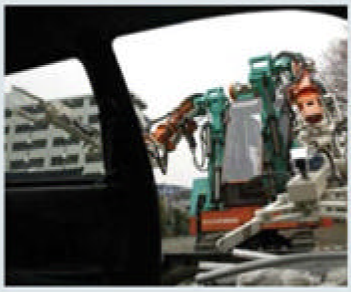
**Power plant**
The T-52 is powered by a large diesel engine, which supplies juice for crawler movement as well as operating each of its moving parts.

**Weight lifter**
Each of the T-52's large hydraulic arms has eight joints and can carry 500kg (1,100lb), or one ton using both arms together.

**Maximum joy**
When remotely controlled, the T-52 is operated with a joystick, with inputs communicated to the mech via wireless LAN and PHS.

**Sand crawler**
The five-ton T-52 moves on a set of crawlers, which can propel the mech at a maximum speed of 3km/h (1.9mph).





## The best of the rest

### 1 Kuratas

The ultimate executive toy, the Kuratas mech allows its owner to ride around in its futuristic cockpit while firing 6,000 BB rounds per minute from its dual, arm-mounted Gatling guns.

### 2 Cybernetic Anthropomorphous Machine

One of the first mechs ever built, the CAM was designed and built for the US Army in 1966 to move cargo and weapons across battlefields.

### 3 Sarcos XOS 2

An exoskeleton that grants its wearer superhuman strength, the XOS 2 is currently being trialled by the US Army, with a finished untethered variant set to enter service in 2020.

### 4 Body Weight Support Assist

Honda's Body Weight Support Assist from is a partial exoskeleton that, once worn, helps to support the user's upper body, taking some of its weight off their legs.

### 5 Raytheon Heavy Lifter

Designed to move large crates, containers and objects, the Heavy Lifter offers its user a high degree of freedom and agility.

### 6 Kid's Walker

The Land Walker's baby brother, the Kid's Walker – which costs about £12,000 ($20,000) – is designed to allow children to pilot their own toy mech while remaining safe.

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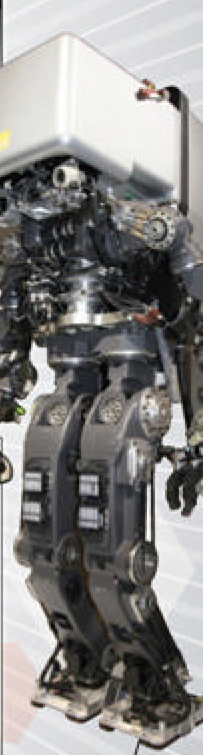
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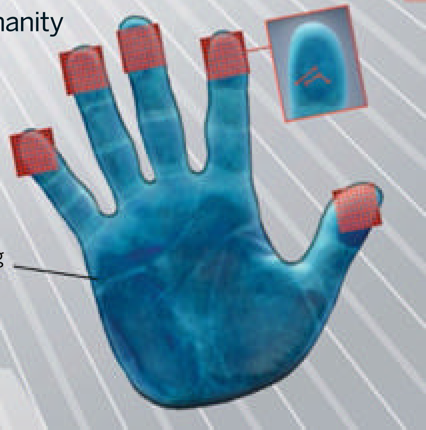
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